AFRL-RH-WP-TR-2012-ЛЛТM

EVALUATING THE USE OF AUDITORY SYSTEMS TO IMPROVE PERFORMANCE IN COMBAT SEARCH AND RESCUE

Terry Rapoch, James Hooker, Andrew Geise, Andrew Hamilton, Valerie Shalin, Jeffrey Cowgill, Robert Gilkey

Wright State Applied Research Corporation

MARCH 2012

Distribution A: Approved for public release; distribution unlimited.

AIR FORCE RESEARCH LABORATORY
711 HUMAN PERFORMANCE WING,
HUMAN EFFECTIVENESS DIRECTORATE,
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

NOTICE AND SIGNATURE PAGE

AFRL-RH-WP-TR-2012-0071 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//signed//
Brian D. Simpson
Senior Engineering Research Psychologist
Battlespace Acoustics Branch

//signed//
William T. Nelson
Chief, Battlespace Acoustics Branch
Warfighter Interface Division

//signed//
Michael A. Stropki
Chief, Warfighter Interface Division
Human Effectiveness Directorate
711 Human Performance Wing

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YY)***
01-03-12

2. REPORT TYPE
FINAL

3. DATES COVERED ***(From - To)***
Oct 2009 – Jan 2012

4. TITLE AND SUBTITLE
Evaluating the Use of Auditory Systems to Improve Performance in Combat Search and Rescue

5a. CONTRACT NUMBER
FA8650-10-2-6048

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)
Terry Rapoch, James Hooker, Andrew Geise, Andrew Hamilton, Valerie Shalin, Jeffrey Cowgill, Robert Gilkey

5d. PROJECT NUMBER
7184

5e. TASK NUMBER
16

5f. WORK UNIT NUMBER
71841623

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Wright State Applied Research Corporation
3640 Colonel Glenn Highway
Dayton, OH 45435

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Materiel Command
Air Force Research Laboratory
711 Human Performance Wing
Human Effectiveness Directorate
Warfighter Interface Division
Battlespace Acoustics Branch
Wright-Patterson Air Force Base, OH 45433

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
711HPW/RHCB

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RH-WP-TR-2012-0071

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
88ABW Cleared 05/29/2012; 88ABW-2012-3075. Report contains color.

14. ABSTRACT: A critical success factor for pararescue jumpers (PJs) executing combat search and rescue (CSAR) missions is maintaining situational awareness while navigating through unfamiliar terrain, mitigating threats to both the PJs and their target, and monitoring the location of team members during a mission. To meet these challenges, PJ's use different technologies, such as specialized video displays. This study continues research to explore the potential for 3D (spatialized) audio displays to enhance performance. With this technology, digital signal processing is used to modify sounds so that, even though they are delivered through headphones, they are perceived to come from specified locations in the external environment around the listener, for example marking the location of a team member, a threat, or a significant landmark. This technology was evaluated in three experimental tasks conducted in an integrated virtual platform (IVP), a two-site distributed virtual environment that is described in the report. The first task found that subjects using personalized audio profiles were able to localize sounds presented in the IVP, but their performance was not as accurate as that observed in the Auditory Localization Facility (ALF) used by the Battlefield Acoustics Branch (RHCB) located at Wright Patterson Air Force Base. The second task found that subjects were able to locate and respond to a threat (sniper) while travelling in a convoy through a representative urban terrain more rapidly when aided by a 3D audio display versus two non-spatial auditory displays. The third task required two subjects to find each other in an urban terrain. They were able to rendezvous more rapidly when they talked to each other through a spatialized communication channel that made their voices appear to arise from their actual location in the terrain than when they used a normal monaural communication channel

15. SUBJECT TERMS
Combat search and rescue, 3D audio, spatialized audio, virtual reality

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT:**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** (Monitor)
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			
Unclassified	Unclassified	Unclassified	SAR	129	Brian D. Simpson
					19b. TELEPHONE NUMBER *(Include Area Code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

THIS PAGE INTENTIONALLY LEFT BLANK.

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

1.0 SECTION 1: SUMMARY 4

2.0 SECTION 2: BACKGROUND 5

3.0 SECTION 3: MANAGEMENT 11

3.1 PROGRAM MANAGEMENT 11
3.2 FINANCIAL MANAGEMENT 12
3.3 TECHNICAL MANAGEMENT 12

4.0 SECTION 4: TECHNICAL PROGRAM 14

4.1 INTRODUCTION 14

TABLE 4.1: HARDWARE COMPONENTS 15

VISUALIZATION 17

TRACKING 17

INTERACTIVES 17

5.0 SECTION 5: EXPERIMENTAL TASK REPORTS 41

5.1 INTRODUCTION 41
5.2 SECTION 5.2 TASK 1: THE INFLUENCE OF LISTENING ENVIRONMENT ON SOUND LOCALIZATION 42
5.3 SECTION 5.3 AURALLY AIDED VISUAL THREAT ACQUISITION 50
5.4 SECTION 5.4 THE IMPACT OF SPATIALIZED COMMUNICATIONS ON TEAM NAVIGATION 56

6.0 SECTION 6: RESULTS, CONCLUSIONS, AND RECOMMENDATIONS 65

6.1 65
6.2 65
6.3 66
6.4 67

7.0 SECTION 7 APPENDICES 69

8.0 SECTION 8: GLOSSARY 121

LIST OF FIGURES

Figure 1. Hardware architecture for the IVP 16
Figure 2. Hardware architecture for the IVP 16
Figure 3. Architecture of the IVP 19
Figure 4. The Auditory Localization Facility at Wright-Patterson AFB. 43
Figure 5. Results from ALF (top row) and VERITAS (bottom row) for Subject P1379. 46
Figure 6. Results for Subject P1401 are plotted in the same manner as Figure 5. 46
Figure 7. Results for Subject P1442 are plotted in the same manner as Figure 6. 47
Figure 8. Results for Subject P1447 are plotted in the same manner as Figure 6. 47
Figure 9. Results for Subject P1481 are plotted in the same manner as Figure 6. 48
Figure 10. Screen shot of a representative terrain from the subject's viewpoint 50

Figure 11. An aerial view of one of the nine 500-m by 500-m terrains, with the path traversed by the convoy during a block of trials shown by the white line. 51
Figure 12. Image of the target (Left) and distracters (Right). 52
Figure 13. (Top) Screen shot of the subject's view at the beginning of a trial. 52
Figure 14. Time to acquire and neutralize the sniper under each of the three audio warning conditions. 54
Figure 15. Mean length of time to acquire and neutralize the sniper as a function of the head-relative sniper azimuth under each of the three audio warning conditions. 55
Figure 16. Two screen shot of an archway used as a landmark in the ALM condition. 59
Figure 17. Screen shot of a water tower used as a landmark in the ALM condition. 60
Figure 18. Average time to complete the rendezvous task each team under the two audio conditions. The black bars show performance averaged across teams. 62
Figure 19. Average duration of push-to-talk button presses under 3D audio and Monaural conditions for subjects in the PJ and TBR roles. 63
Figure 20: IVP System Architecture 92
Figure 21 : Representative IEC Experiment States...94
Figure 22: Configuration Page 109
Figure 23: Processing Page 110
Figure 24: Output Page 111

EXECUTIVE SUMMARY

The ability of para-jumpers(PJ's) to successfully execute combat search and rescue (CSAR) missions depends on their having persistent and comprehensive situational awareness. To accomplish this, the PJs must effectively deal with many different factors. Particular challenges include navigating through unfamiliar and hostile terrain, mitigating and/or eliminating threats to both themselves and those they are rescuing, and knowing the status and location of their team members and the target throughout a mission. To help meet these challenges, PJs have evaluated and deployed different technologies, including specialized video and heads up displays. The research carried out through this cooperative agreement focused on the continuing evaluation of the potential for synthesized, spatialized audio to be used as technology for CSAR missions capable of improving mission performance by complementing existing audio communications.

Humans can locate the source of sounds very quickly and reliably. Spatialized audio takes advantage of this capability using software to manipulate an incoming audio signal so that a subject perceives it to be coming from a particular location in terms of its azimuth and elevation. Because of the variations between individuals in terms of the specific characteristics of their auditory systems, such as their head size and the shape of the ear, part of the process in exploiting spatialized audio is the measurement of the effect of these factors in a standardized environment, such as the Auditory Localization Facility (ALF) at Wright Patterson Aid Force Base and compiling them into a unique set of signal transformations. This process is well understood and has already been demonstrated in many experiments. In 2005, research was started to apply this technology to assist PJ's in CSAR missions, generating spatialized signals to assist them in navigating to a target and being made aware of threats to them en route.

It does not matter where the actual sound source originates in terms of how it is perceived after the software manipulations. Knowing the position of an individual's head, it is possible to create a sound that will be localized correctly. This has created at least two different ways of using specialized audio. The first is to have the sound localized to the actual speaker, for example a team member walking down another street. Another is to have the speaker localize their voice so it appears to be coming from a particular location in the environment. For example, the speaker could be an observer at another location on the ground, flying overhead or in a command center or interpreting sensor information from an RPV or satellite. Another possibility is that a single audio signal could be manipulated so that multiple individuals in a situation proceeded to come from a common point in the environment. Such a capability would greatly simplify team communications and make them far more reliable. However, there is a significant amount of additional research and development that needs to be completed before an operational system can be deployed. The research performed during this project is another step in that direction, building on a number of previous research initiatives.

The experiments described in this report that were performed to evaluate the effectiveness of a spatialized audio over other audio communications were conducted using immersive virtual environments, sometimes called virtual reality. While the use of virtual environments for the

evaluation of technologies, like spatialized audio, is technically challenging, it also has certain significant advantages, including:

1. VR creates a compelling, realistic environment in which to perform activities comparable to those that would occur during an CSAR mission,
2. Responses of individuals performing tasks within the environment can be very precisely measured and that information used to analyze performance,
3. Nature of the mission and the environment in which it occurs can be modified relatively easily,
4. Multiple repetitions of particular task can be performed in a reasonable periods of time, and
5. Non-professionals can be trained to operate in the environment relatively easily while still being able to effectively demonstrate the effect of the technology be studied.

The proposed research program was to focus on four particular areas related to the operation and application of spatialized audio within the context of CSAR missions.

1. Addressing the practical issues with respect to the need for individualized audio profiles to deliver the level of accuracy in identifying the locations
2. Looking at the effect of ambient noise on the accuracy of location determination by subjects
3. Evaluating the effectiveness of different types of external audio signals, i.e. those that might come from an observer, on the ability to locate and eliminate threats to a vehicle convoy in a simulated urban environment, and
4. Having a PJ and target searching for each other in an urban environment while either avoiding or eliminating potential threats. This last task also collected the audio communication between subjects to determine if having spatialized audio versus normal audio change the nature of those communications and their effectiveness.

The technical development required to create the environment in which these tasks could be performed was extensive. While the technology, both hardware and software are getting easier to work with, the development of effective, reliable virtual environments with a full range of capabilities with respect to motion and interaction quires complex integration and the development of new application capabilities to support component integration. An important focus of this particular project was to find more clearly the architectural basis for a multisite, integrated virtual platform (IVP) and to start to complete the development of the necessary components within that architecture. A great deal was accomplished and learned about what the creation of an effective virtual environment entails, but also the tremendous amount of information that can be derived from it. Of particular note, was the understanding gained with respect to the scope and complexity of data that virtual environments can and do generate in the course of an experiment. Well not fully solved, this particular challenge is now better understood.

The results of the experiments demonstrate that spatialized audio does require individualized audio profiles to operate accurately and reliably. In addition, the vehicle convoy and search tasks demonstrated that spatialized audio delivers significant improvements over standard monaural communications, but there was not time to evaluate what impact ambient noise might have on the

practicality and effectiveness of the spatialized audio technology. However, enough was gained to suggest that additional research into the use of specialized audio would be fruitful, and that the use of virtual environments provided an effective vehicle in which to perform meaningful experiments on the specific issues that could lead to the eventual operationalization of the specialized audio technology.

Another result of the work was the development of a generalized model to link mission related performance with human performance using virtual environments as one vehicle to do this. The key element is to understand the drivers from a human perspective that results in improvements in performance against mission objectives. Without this, the process of improvement, particularly where a human is “in the loop”, is become “hit or miss”. This is not applicable approach, a point that is made abundantly clear in the United States air forces strategic document “Technology Horizons” that establishes the need to increase human performance as one of the key outcomes from the plan. The work with respect to CSAR missions and the performance of PJs represents only one small opportunity to develop methods that follow this approach and apply technologies, such as the use of virtual environments, 2 very quickly discern potential opportunities for significant improvements and to define the path forward both for research and the commercialization all of appropriate technologies.

1.0 SECTION 1: SUMMARY

This final report breaks down the work that was done in cooperative agreement FA8650-10-2-6048 into the following sections:

SECTION 2: BACKGROUND

This section discusses previous work that was done with respect to the impact of spatialized audio on performance in CSAR missions using simulations in virtual environments that led to the current program.

SECTION 3: PROGRAM MANAGEMENT

This section deals with the activities and approaches used to manage:

- Program activities
- Financial aspects of the program
- Technical development required to support the research, and

SECTION 4: TECHNICAL PROGRAM

This section covers the technologies used in the Integrated Virtual Platform (IVP), its physical and application architectures, and the development and integration of hardware, and software components to support the research task. The section also includes a summary of the results, conclusions and recommendations based on the technical activities undertaken during the program.

SECTION 5: EXPERIMENTAL TASK REPORTS

This section describes the three experimental tasks that were completed including the method, results, and discussion. The reports for Tasks 3 and 4 are in the format of the technical papers that were developed from the work that was done and submitted for presentation at upcoming conferences.

SECTION 6: RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

This section separately summarizes the broad findings and implications of our technical development efforts and experimental research.

SECTION 7: APPENDICES

This section includes requirements and other supporting technical documentation.

SECTION 8: GLOSSARY OF TERMS

2.0 SECTION 2: BACKGROUND

Problem

Threats on a battlefield can emerge quickly and without warning. Soldiers or observers need to be able to coordinate with one another in order to locate and address threats as quickly as possible. Ground or air assets must be able to direct friendly forces to a threat in order to protect their allies and effectively neutralize the threat. In order to accomplish this, speakers must be able to convey important points of mutual interest (Ephrem et al., 2008). Such coordination requires that the speaker know the whereabouts of friendly forces and hostile threats and orient friendly forces to the threat once it is located. Spatial audio has shown great promise in both communication and navigation, and we believe it holds promise for target identification and localization, as well.

Display options

The current method of conveying location information is verbal description. These descriptions can be effective, but there are several drawbacks that make them less than ideal. Verbal descriptions are complex and time-consuming. Descriptions may be ambiguous and soldiers in different locations relative to a threat or point of interest require different descriptions, further complicating coordination (Ephrem et al., 2008). Threat information can be time-sensitive, and location information during battle must be real-time, intuitive, and unambiguous in order to be effective (Ephrem et al., 2008). Fortunately, recent technological advancements have made it possible to present soldiers with real-time information about the environment (Gilkey, Simpson, Brungart, Cowgill, & Ephrem, 2007). There are several potential methods of delivering such information to the warfighter.

Verbal descriptions, Global Positioning System (GPS) coordinates, visual displays, and spatial audio displays are all viable options for delivering real-time information to warfighters on the ground. Audio displays offer several advantages over other display types, however. As previously discussed, verbal descriptions are complex, time-consuming, and potentially ambiguous. Different descriptions are required for warfighters in different locations relative to the point of interest (Ephrem et al., 2008). GPS coordinates are exact and agnostic as to warfighter location, but conveying GPS coordinates requires complex communication that may be vulnerable to transcription error, and still requires receiving soldiers to calculate their own GPS position relative to the threat (Ephrem et al., 2008). Presenting information on a map or other visual display is unambiguous, but may be vulnerable to map-environment translation error. Map displays also prevent heads-up, hands-free operation, requiring the warfighter to divert attention away from the surrounding environment (Ephrem et al., 2008).

Why spatial audio?

Spatial audio displays offer several advantages over verbal or visual displays. Spatial audio displays take advantage of human binaural hearing to present spatial information through auditory stimuli as it would occur in the real world. This allows the operator to determine the location of a sound source, track multiple sources, and organize the environment more effectively than through current display systems (Simpson, Brungart, & Popik, 2007). While other displays may be ambiguous, distracting, or increase workload, spatial audio displays are intuitive and do not impose additional processing demands on the operator (Simpson, Brungart, & Popik, 2007). They may also be less distracting than other types of displays (Gilky et al., 2007). Audio displays can help reduce the warfighter's visual workload and can help disambiguate information (Simpson, Brungart, & Popik, 2007). Spatial audio displays can be used for directional cuing of threats, target acquisition, or navigation (Ephrem et al., 2008). They can also disambiguate communication channels to identify the speaker (Ephrem et al., 2008).

Auditory warnings are so attention demanding that changes in the auditory displays are nearly impossible to ignore. This feature makes audio displays ideal for conveying critical information (Simpson, Brungart, & Popik, 2007). The audio system can also monitor the world in 360 degrees, unlike the visual system (Simpson, Brungart, & Popik, 2007). This makes spatial audio particularly well suited for cuing threats in a dynamic, uncertain environment, where a point of interest may not be in the direction in which the listener is looking. Spatial audio displays offer the ability to project a speaker's voice to the location of a referent, allowing intuitive, unambiguous, real-time coordination about locations. Spatial audio renders operator position irrelevant, and allows heads-up and hands-free operation (Ephrem et al., 2008). Spatial audio displays are nearly ideal for communicating the location of a threat to multiple operators unambiguously and in a short amount of time.

Spatial audio basics

Spatial audio works with human binaural hearing to generate sounds that behave as if they were generated by the surrounding environment. Sounds are presented to the eardrum in the same manner that they would be presented in the real world. The brain interprets the artificial signal and the natural signal in the same way (Simpson, Brungart, & Popik, 2007). A listener's head, pinnae, and torso all affect the way that a sound presents to the eardrum and allow humans to localize sound sources. Interaural time differences (small differences in onset time between eardrums) and interaural level differences (differences in sound intensity) also aid localization (Simpson, Brungart, & Popik, 2007). The changes on sound imposed by the pinnae, head, torso, etc. can be captured using microphones embedded in the ear. These measurements are used to generate a head-related-transfer function (HRTF). HRTFs are used to generate signal filters in order to create stimuli that match the real world (Simpson, Brungart, & Popik, 2007).

Spatial audio is implemented using GPS and a head tracker (Gilky et al., 2007; Simpson, Brungart, & Popik, 2007). Head trackers allow the display to account for listeners' head movement in real-time when generating signals (Simpson, Brungart, & Popik, 2007). Listeners use head movement to clarify sound sources and to place stimuli in the "auditory fovea" for improved clarity (Simpson, Brungart,

& Popik, 2007). The ability to utilize head movement is especially useful when making front-back distinctions (Simpson, Brungart, & Popik, 2007).

Past research

This study is part of a larger body of work to assess the utility of spatial audio for communication, navigation, and localization tasks. Air Force Research Lab (AFRL) studies have demonstrated the utility of spatial audio for disambiguating multiple communication channels, thereby reducing workload and improving situational awareness compared to traditional systems (Brungart & Simpson, 2002; Brungart & Simpson, 2005).

Prior studies in the AFRL have compared standard audio to spatial audio using a God's-eye view of a virtual maze with a hidden downed pilot (Ephrem et al, 2008). A ground operator searched for a downed pilot in the maze while avoiding hostile forces and ignoring friendly forces. Participants located the pilot more quickly and were shot by hostile forces less frequently with spatial audio compared to standard audio (Ephrem et al., 2008). A study using a similar scenario compared navigation based on waypoint navigation to navigation based on bearing information delivered via visual display or spatial audio (Gilky et al., 2007). Spatial audio was faster to completion than the visual display, offering the advantages of a decluttered visual field and increased situational awareness (Gilky et al., 2007).

The current program of study is intended to determine the utility of spatial audio for localization tasks. Previous research at the AFRL has demonstrated that spatial audio can improve performance during visual search and localization tasks. This effect is especially evident when the visual scene is complex, as in an operational environment (Simpson, Brungart, & Popik, 2007).

The Integrated Virtual Platform (IVP)

The IVP is the environment used to support the current research program. This facility was collaboratively developed by Wright State University (WSU), the Wright State Applied Research Corporation (WSARC) formerly daytaOhio and the Air Force Research Laboratory (AFRL) as a flexible, extensible platform to conduct experiments studying human performance using immersive virtual environments.

In 2005, Wright State University (WSU) started the initial work on using virtual environments for the combat search and rescue CSAR) applications. The IVP was developed in 2007 in a project funded by Air Force Research Lab (AFRL) Sensors Directorate. It linked together WSU's Virtual Environment Research, Interactive Technology, And Simulation (VERITAS) facility located in building 441 at Wright Patterson Air Force Base (WPAFB) with the Wright State Applied Research Corporation's (WSARC) iSpace™ located in the Appenzeller Visualization Lab (AVL) in the Joshi Center on the WSU campus.

The platform used two protocols for supporting distributed simulations, High Level Architecture (HLA) and Distributed Interactive Simulation (DIS) combined with scenario and artificial intelligence

(AI) elements using commercial off-the-shelf (COTS) combined with custom developed simulation and visualization applications. These elements were designed so that they could be run on different visualization hardware with little or no modification. The first version of the IVP was demonstrated to the program sponsors from AFRL in late 2007 and there were a continuing series of refinements to improve reliability and consistency of IVP operation while supporting experiments in 2008 and 2009. All these experiments were done to assess the use of specialized (3D) audio displays in the context of CSAR missions in urban environments.

In 2009, WSARC developed the proposal that became the basis for agreement FA8650-10-2-6048 in a collaborative development effort with a team led by Dr. Robert Gilkey from WSU. The title of the program was " Evaluating the Use of Auditory Systems to Improve Performance in Combat Search and Rescue Missions" and the focus was to continue the effort toward developing an operational, spatialized audio system that could be deployed in the field. During the same period, WSARC made additional investments to renovate WSU VERITAS facility with funds from the state of Ohio 3rd frontier Project. These upgrades included new servers and projector systems that were compatible with the ones used in the AVL.

Statement of Work

The Statement of Work (SOW) for FA8650-10-2-6048 included four specific research tasks that built of previous efforts:

1. Assessment of the need for individualized audio profiles to be able to use a spatialized audio display reliably and accurately.

   This has important operational considerations in terms of deploying such a system in the field. These profiles adjust the performance of the spatialization software with respect to Head Related Transfer Functions (HRTF) by taking into account differences in the auditory systems between individuals due to the anatomy of the ear, head and other factors. If it were shown that a generic profile, or HRTF file, could be used, then this would make deployment far simpler. However, if individualized HRTF files were needed, then procedures would have to be developed to both create them and make sure that they were correctly loaded into the software for each user.

2. Evaluation of the impact of ambient noise on the accuracy of localization achieved by the use of spatialized audio.

   This is another important operational consideration since it is clear that PJs and others in combat rely on their sense of hearing to maintain situational awareness and respond effectively to potential threats in the environment.

3. Analysis of the effectiveness of spatialized audio in team-based search activities.

   Comments from previous meetings with PJs indicated that understanding the location of other team members was important and could be very time-consuming. Spatialized audio

could improve the situation by providing unique localized sounds for each team member, possible combining their voice with other sounds during communications.

4. Assessment of the impact of using spatialized command and control communications on mission performance.

   Because the specializing software can manipulate an audio signal from any source and localize it correctly within a PJs environment, this could provide a significant enhancement to communications being sent. This would require a means of annotating a location within an environment so that the signal or voice would be perceived as coming from that location. This would appear to be less distracting than other alternatives like having to look down at the display and so a spatialized audio display could be an excellent vehicle for use in situations with heavy task loads, such as CSAR missions.

In 2009, while the WSARC proposal was in process, the WSU team conducted an experiment using the IVP to evaluate the use of spatialized audio to support a PJ on the ground from a helicopter loitering above an urban environment. The results of this experiment were inconclusive. As a result, it was decided that the project objectives should be modified to conduct more research to verify the performance of the spatialized audio display using more sophisticated virtual testing environments and experiments. Unless this was done, the results of any further experiments on the effectiveness of 3D audio for CSAR missions would be compromised. This decision was made in March 2010 in collaboration with the team and AF Program Manager.

The result was a change in the definition of the tasks outlined in the SOW for FA8650-10-2-6048.

- Task 1 was expanded in scope to include; Task 1.1 to validate and verify the spatialized audio system used in the IVP, and Task 1.2 to directly compare subject performance in the IVP with that in the Auditory Localization Facility (ALF) used by the Air Force Research Lab (AFRL) at Wright Patterson Air Force Base (WPAFB). The report on this task is entitled " The Influence of Listening Environments on Sound Localization"
- Task 2 to evaluate with effect of ambient noise was dropped entirely due to time constraints.
- Task 4 was completed before Task 3 and modified to be a comprehensive assessment of the performance of spatialized versus semantic (descriptive) and monaural communications. Subjects travelled in a fixed position as part of a convoy moving through an urban environment and had to deal with sniper attacks. It did simulate communications from an external observer, such as a command center or UAV operator, which was part of the original Task 4. Th report on this task is entitled " Aurally Aided Visual Threat Acquisition"
- Task 3 was simplified to involve two subjects trying to locate each within an urban environment using spatialized and normal monaural communications, including the role of landmarks in enabling the activity. The report of this task is entitled "The Impact of Spatialized Audio on Team Navigation"

Information on these changes was included in the quarterly reports that were issued during the execution of the project.

References

Brungart, D. S., & Simpson, B. D. (2002). The effects of spatial separation in distance on the informational and energetic masking of a nearby speech signal. *Journal of the Acoustical Society of America 112,* 664-676.

Brungart, D. S., & Simpson, B. D. (2005). Optimizing the spatial configuration of a seven- talker speech display. *ACM Transactions on Applied Perception, 2,* 430-436.

Ephrem, A., Finomore, V., Gilky, R., Newton, R., Romigh, G., Simpson, B., et al. (2008). An "audio annotation" technique for intuitive communication in spatial tasks. Paper presented at the annual meeting of the Human Factors and Ergonomics Society.

Gilky, R., Simpson, B., Brungart, B. Cowgill, J., & Ephrem, A. (2007). *3D audio display for pararescue jumpers.* Paper presented at the 51st annual meeting of the Human Factors and Ergonomics Society.

Simpson, B., Brungart, D., & Popik, D. (2007). *The application of spatial audio displays in complex environments.* Paper presented at the Human Systems Integration Symposium.

3.0 SECTION 3: MANAGEMENT

3.1 Program Management

Successful completion of the program defined by agreement FA8650-10-2-6048 required close collaboration of the teams from the Wright State Applied Research Corporation (WSARC), formerly the Wright Center of Innovation for Advanced data Management and Analysis, Inc. (daytaOhio) and the principal subcontractor, Wright State University (WSU). As required, additional subcontractors were engaged form time to time to address specific technical areas. Also, the WSARC team was fortunate to have the sustained involvement and support of Dr. Brian Simpson, the Program Manager and Mr. Vic Finomore, both from Human Effectiveness Directorate, Warfighter Interface Division, Battlefield Acoustics Branch (RHCB) of the Air Force Research Lab (AFRL) at Wright Patterson Air Force Base (WPAFB) during the entire program providing insight and expertise.

This program team usually met every two weeks to review the progress on the definition and design of the experiments for each of the tasks described within the Statement of Work (SOW) for the agreement and the related technical development. In addition to these, the program team held longer meetings, structured as workshops to complete more in-depth reviews of the experimental and technical requirements related to a particular task. There was a session in late April 2010 to review the approach for designing and developing a new urban terrain that create larger, more flexible and varied environments. Another session on August 30, 2010 defined the detailed plan for Task 4. Throughout the course of the work on this program, members of the team made themselves available to participate in these sessions and worked in a collaborative manner its complex experimental and technical aspects.

To facilitate the meetings and provide a consistent format for the agenda and associated material, WSARC used project funds to acquire a collaborative environment from the Mind Jet Corporation called Catalyst™. This proved to be an effective tool to support meetings and provide a repository for the different types of documentation and materials that were prepared. The Catalyst™ site was only licensed for one year consistent with the projected length of the contract for all participants and is still maintained by WSARC to keep the material available. In addition to the meeting notes, the WSARC program manager received monthly reports from all subcontractors and issued quarterly reports to the Dr. Simpson, the AFRL Program Officer, the AFRL Contracts Office, and the Administrative Contract Officer responsible for oversight of this agreement.

The initial term of the agreement was 15 months running from November 2009 to February 2011. However, as the result of changes to the scope in certain areas of the project, additional time was requested to complete the work and issue the final report. The WSARC program manager requested no-cost extensions, initially extending the end date of the contract to June 30, 2011 and ultimately to January 31, 2012. Both these were approved and the WSARC project manager is appreciative of the consideration given to these requests by the Program Manager and other representatives from the Air Force.

3.2 Financial management

Agreement FA 8650–10–2–6048 was set up as a firm fixed price agreement. WSARC established a proposed set of internal rates for the agreement, which were conditionally approved and finalized in 2011. In addition, DCAA completed an audit of WSARC's financial and time recording systems and procedures, and deemed them satisfactory in March 2010. It was agreed that WSARC issue invoices on a quarterly basis through Wide Area Work Flow (WAWF) in advance to assist the company in managing its cash flow commitments with respect to the agreement. WSARC adjusted invoices in the subsequent quarter for any discrepancies in time or billing amounts. In January 2011, WSARC requested an adjustment to the budget reallocating funds from the WSU subcontract and this was approved. This change did not affect the overall value of the contract. At the date of this report, final steps are being taken to close out the financial aspects of the agreement working with the Administrative Contract Officer and his staff.

3.3 Technical management

To complete the program and three experiments involved a significant amount of technical development and related integration and testing. Jeff Cowgill from WSU was the technical leader in this effort, building on his many years of experience working in the VERITAS facility and also in WSARC's Appenzeller Visualization Lab (AVL). WSARC hired a senior programmer, Jim Hooker, and added a summer intern from the University of Dayton, Andy Giese who continued to work on the project on a part-time basis. WSU graduate students also did excellent work throughout the program. As needed, WSARC also engaged subcontractors from time to time to address specific technical areas. While the technical team attended all of the regular program meetings, they also held a separate set of meetings on a regular basis, often on the week between the program management meetings, to review progress on the technical development. They also held separate in-depth sessions and workshops to solve specific technical challenges and/or establish detailed requirements. The team was also responsible for all of integration and testing, including the detailed pre-experiment tests of the virtual environments. This was a critical, but very time-consuming activity on part of the team and additional comments on this testing requirement are included later in this document.

The technical development work followed a traditional development cycle starting with the design activities based on discussions with the research teams and the development of system requirements. The requirement documents are included as appendices to this report. For software development, the team set up a common source code repository and maintained it, checking in and out particular elements as work was being done to complete them. Testing was a major activity of the technical team, and beyond the normal unit and system level testing there were the walk-throughs and reviews with the experimental teams. As noted, the team completely verified the technical set ups for all experimental trials to ensure that configuration variables and controls for the experiment were operating correctly before any subjects were tested. This extensive testing was necessary for two reasons:

1. Operation of the IVP requires the coordinated execution of many different software and hardware components and associated data sources and files. It was essential to make sure that these configurations were properly set up and the procedures initiated in the correct sequences,
2. Subjects were not available on call and so it was important to minimize the possibility for technical problems when they were in the environment since making up for such technical problems was difficult and costly, and
3. Avoiding technical problems limited repeat exposures for a subject to the environment that could result in learning and affect results.

In the course of the program, the technical team also had to validate and verify the operating environment in which the subjects performed. The need for this became evident from an experiment run immediately prior to the start of this agreement. The inconclusive results pointed to issues with respect to the reliability of the basic hardware and software configurations that were used by the subjects. As a consequence, Task 1.1 was defined and completed to provide the end-to-end validation and verification of the audio environment and all of the software controlling it. A similar process of validation and verification had to be done for the environment in the AVL.

4.0 SECTION 4: TECHNICAL PROGRAM

4.1 Introduction

The technical program included the design, development, and testing of the Integrated Virtual Platform (IVP) to support the experiments to assess the impact of audio display systems on performance during CSAR missions. In turn, this involved the integration of hardware, software and communications components, some of which were commercial products and others of which had to be custom developed. Another component of the technical program was providing immediate support for the experiments, both the testing of experimental scenarios before any trials were executed and providing technical oversight and assistance during actual data collection.

To be effective, the IVP required an architecture to organize the hardware, software and communications components to deliver the range of capabilities required for the proposed research and experiments. This was developed early in the program and the team used it consistently to organize and manage development, testing and experimental activities. As a result, this section uses the developed architecture to organize and explain the elements of the technical program.

The architecture is divided into two main parts:

1. Physical architecture - describes how the various hardware and physical communications components are linked and this is illustrated in Figure 1 and 2
2. Software or Application architecture - describes how the various programs, application program interfaces (API) and tools interact to create and present the virtual environments, then record and analyze the experimental data

Separate sub-sections describe each of these in more details and the last part of this section sets out:

1. Results of the technical development activity,
2. Conclusions or “lessons learned” that can be drawn from it, and
3. Recommendations regarding future directions for the development and use of the IVP for evaluating technologies to improve human performance for CSAR and other applications

4.2 Physical Architecture

The IVP consists of two separate physical facilities:

1. The **VERITAS** facility in Building 441 at WPAFB which is a 5 sided (4 walls and a floor) virtual environment, and
2. The **AVL** facility which is a 4 sided (3 walls and a floor) BARCO iSpace™ virtual environment.

These operate on independent LANs and are connected to each other through a WAN enabled on Internet2. Routers at both ends deal with protocol translations between the native DIS environments in each location and allow DIS messages to traverse the Internet2.

Table 1. Hardware components

Component	**VERITAS facility**	**AVL Facility**
Processing	5 - BOXX Technologies Dual Xenon E5420 2.5 Ghz Nvidia Quad Fx56000 Win XP Pro 32 Bit Other Servers 1 - Audio 1 - Tracking Systems and Devices 1 - Simulation Servers To Support AI	4 - BOXX Technologies Dual Xenon E5420 2.5 Ghz Nvidia Quad Fx56000 Win XP Pro 32 Bit Other Servers 1 - Audio 1 - Tracking Systems and Devices
Visualization	5 - Barco Galaxy Nw-12 Projectors 1200x1200 Pixels Real-Id Crystal Eyes Shutter Glasses	4 - Barco Galaxy Nh-12 Projectors 1400x1050 Pixels Real-Id Crystal Eyes Shutter Glasses
Tracking/Interactives	Intersense 900 (Acoustical) Head Mount And Hand Held Wand	Arrt Track (Optical) Head Mount And Hand Held Wand
Communications		
Data	WAN - Internet 2	WAN - Internet 2
Audio	Senheiser Hmd-280 Xq Headsets	Senheiser Hmd-280 Xq Headsets
DIS Messages	DIS Gateway	DIS Gateway

Figures 1 and 2 below shows the hardware architecture for the IVP.

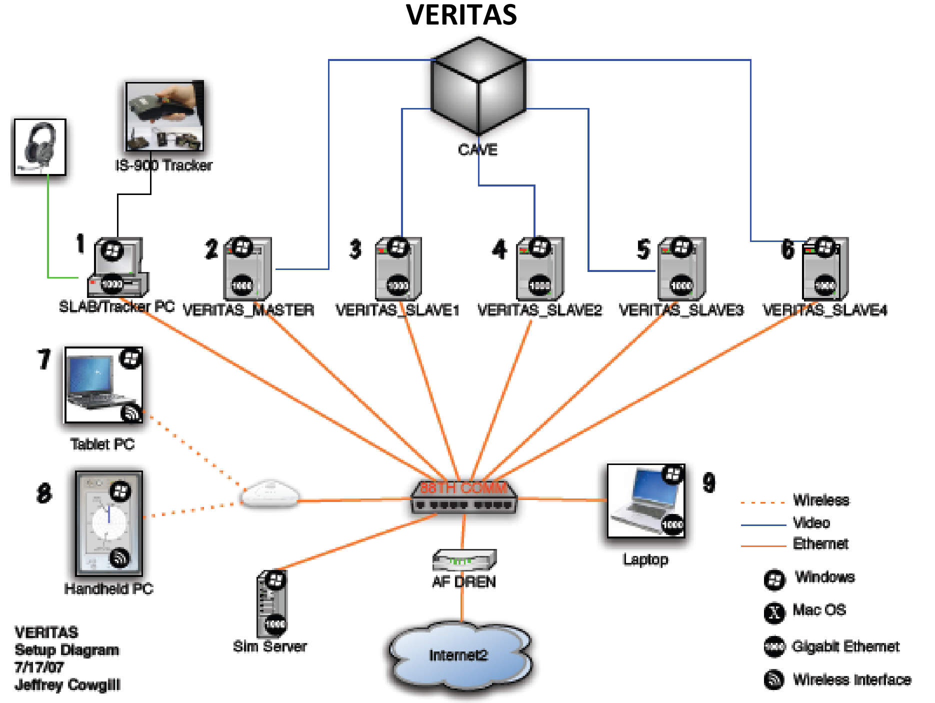


Figure 1. Hardware architecture for the IVP

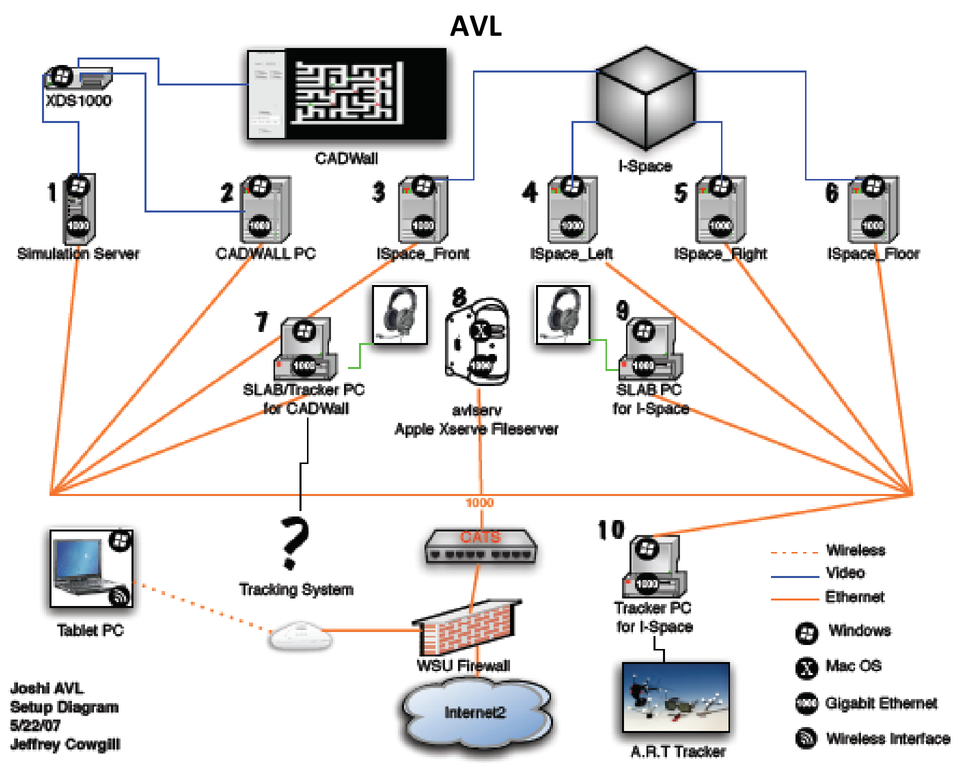


Figure 2. Hardware architecture for the IVP

The following paragraphs provide additional detail on the various hardware components.

Processing

The video processors in both the VERITAS and AVL facilities were upgraded in 2008 and 2009 and are specifically designed to support the high speed rendering of images required to support the IVP. WSARC used funds from the Ohio Third Frontier program and the Ohio Department of Development to pay for these upgrades.

Visualization

The projectors in the VERITAS facility were upgraded with funding from WSARC in 2009 to DLP™ based units from BARCO compatible with the units used in the AVL. Again, WSARC used funds from the Ohio Third Frontier (OTF) program and the Ohio Department of Development (ODoD) to pay for this upgrade to strengthen the collaboration with AFRL, the 711th Human Performance Wing (HPW) and the Human Effectiveness Directorate (RH).

Tracking

Tracking is an essential part of the immersive virtual environment, providing the information on both the position (x, y, z) and attitude (pitch, roll, yaw) of individual and devices, i.e. in six degrees of freedom (6dof) within the virtual environment. Tracked elements included the subjects' heads and hand devices (pointer, gun, grabber).

In the VERITAS, the head-tracker was a A 6-DOF tracking system (Intersense IS-900), consisting of a head- tracker and a tracked, hand-held Wand input device communicated with the PCs via another 2.4-Ghz Xeon PC (Dell) over Ethernet. A trigger button on the bottom of the wand allowed subjects to fire their weapon.

Interactives

These included:

- The handheld devices, a Flystick or Wand that subjects used to interact with the environment and
- The devices used to control motion of the subject within the environments.

Communications

The communications environment included two distinct types of infrastructure elements:

1. **Data network** - this supported the operation of the IVP and allowed the recording of interactions within the environment for subsequent analysis. This included local area networks (LANs) at the two virtual sites within the IVP and the wide area network (WAN)

network components connecting the VERITAS facility in Building 441 on WPAFB with the AVL in the JRC on the WSU campus.

2. **Audio network** - this allowed voice and other audio communications to and between individuals to be transmitted over the network and arrive in the respective virtual environments. Since the goal of the program is to evaluate the impact of auditory systems on performance, the IVP has specialized audio equipment including headsets and transmitters that operate wirelessly so subjects are not constrained as they perform the various experimental exercises. The upgrading of the environments to wireless equipment took place in 2007 as part of the program funded by AFRL Sensors Directorate (RY) that developed the IVP.

   One critical aspect of the program was the transition to a homogeneous DIS environment, allowing the use a technology called “DIS radios” that

    a. Improved the fidelity of the sound that could be transmitted and received within the environment to support wideband audio signal needed to accurately elevation perception and front/back discrimination and
    b. Provided compatibility with other Air Force technologies for recording and analyzing voice communications.

3. **DIS Messages -** these messages traverse the WAN to synchronize activities in the respective environments. In moving to an all DIS environment, it became necessary to implement DIS gateways at each locations to format DIS message into UTP for transmission across the WAN and then convert them back into DIS messages.

4.3 Application Architecture

The software architecture provides the framework for understanding the software components and how they provided the capabilities needed in the virtual environment to support the three experiments. At a high level, the architecture was developed to deliver the following basic functions in the IVP.

1. **Rendering** - applications to create the environment including terrain, buildings, objects, etc.
2. **Simulation** - tools to execute events and activities within the environment involving subjects
3. **Motion** - applications to support motion of subjects through the environment and the monitoring of that including navigation and orientation
4. **Interaction** - applications to support interactions occurring within an environment, including what areas were being traversed, contact with buildings, encounters between individuals, such as shooting events, and communications between subject in an environment.
5. **Coordination** - the DIS (Distributed Interactive Simulation) protocol provided the messaging backbone in the IVP, keeping track of entities and coordinating events within and between the IVP environments, such as starting and stopping events.
6. **Data capture and analysis** - a system to collect and manage the data created by experiments in the IVP used for performance analysis and event re-creation.

The architecture of the IVP includes the following elements as shown in Figure 3 below. Separate sub-sections describe the purpose of the component, the key development work that was done during this project, and how it supported the experimental tasks. The task information is presented in the order in which the experiments were performed starting with Task1, then Task 4, and Task 3.

Applications were developed in C++ using Visual Studio 2005 (Microsoft), Vega Prime API (Presagis), DI-Guy (Boston Dynamics), and Immersive Module for Vega Prime (Mechdyne). Table 1 summarizes the overall development activities within each element of the architecture and for each task.

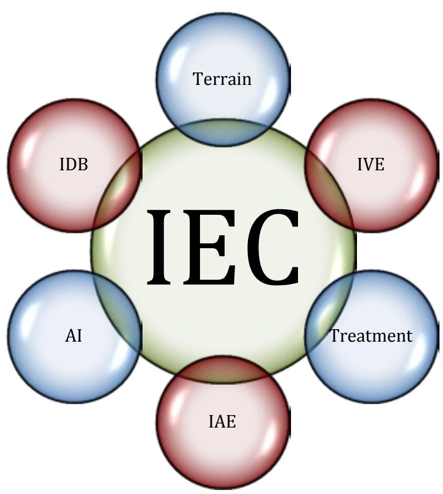


Figure 3. Architecture of the IVP

Table1. Application Components

Component	Common	Task 1	Task 3	Task 4
IVP	DIS DIS Routers	ALF (Sphere) analog environment	Implement DIS Routers	
IEC	C++	IEC v1.0 with ALF simulation controls	IC v1.0 XML control file	IEC v2.0 with convoy/sniper simulation Scenario Generator XML control file
IVE	• Vega Prime API • Immersive module for VEGA Prime • Mak VR Forces	ALF (Sphere) analog environment	Multiple start points and Land Mark toggle	Convoy motion model with pop-up sniper/distractors
IAE	SLAB 3D v6.5.0 DIS Radios	ALF sound analog	DIS radios Multiple spatial audio displays for localizing team and annotation	DIS radios 3 sounds prompts - mono/semantic/spatial
IDB	Mak Data Logger	MAK IEC collection	MAK IEC/IVE collection Audio file collection	MAK IEC/IVE data collection
Terrain	Presagis CREATOR PRO	ALF(Sphere) analog	Urban tiles	Urban tiles
AI	• Mak VR Forces • Boston Dynamics (DI-GUY)		Hostiles/civilians	Sniper/civilian distractors
Treatments	XML file	1 Audio - Spatial	• Tile • Start point • Landmark • 2 Audiol	• Tile • Time of day • Path/active snipers • 3 Audio

Integrated Virtual Platform (IVP)

Purpose

This is the overall platform that allows the interoperation of activities between the two virtual environments that make up the IVP; VERITAS and AVL. The purpose of this platform is to facilitate the use of virtual environments for a diverse set of applications, including the testing of new types of technologies to improve human and mission performance. The IVP was designed to provide flexibility in terms of how environments are created, the activities that can be performed within them, and the types of technology platforms on which they can run. Another important component of the IVP architecture is the inter-site communications infrastructure, including DIS routers at each end and the WAN and LAN connections to and from these routers.

Shared development

1. **All DIS environment**

   The major change in the IVP was the implementation of a homogeneous DIS environment. This was done to support the delivery of wideband audio signals between sites necessary to support elevation perception and front/back discrimination Previous projects used Team Speak, a COTS Voice Over Internet Protocol (VOIP) software), which has more limited capability. As a result, there was concern that some of the subtler effects particularly elevation were being compromised. In addition this change to DIS was made to ensure compatibility with other AF and RHCB development activities, including the handling of multichannel communications. To make the transition to a homogeneous DIS environment, the team defined specific DIS messages to support the design requirement of the experiments. In the appendices, there is material on

   - The DIS protocol, an accepted IEEE standard, and
   - The various messaging elements used to control and manage the distributed events and activities within the IVP.

2. **DIS gateways**

   A consequence of moving to the all DIS environment was the need to install DIS routers in addition to the WAN routers used to connect the VERITAS and AVL. These routers or gateways allowed DIS messages to be converted to User Datagram Protocol (UDP), transmitted across the Internet2 using Transmission Control Protocol (TCP), and then translated back into DIS messages without any significant latency or delay so that events in the two virtual environments remained correctly synchronized

Task related development

Task 3

This task involved individual subjects in each location interacting within the same virtual environment. Supporting this required:

- Implementation of the DIS routers to facilitate moving to an all DIS environment, and
- Completing the validation and verified procedures developed in sub task 1.1 for the audio environment in both the iSpace and VERITAS facilities.

Matt Middendorf of Middendorf Scientific Services Inc. deserves particular thanks for the work in getting the DIS router software from the Joint Services Action Force and helping the team to implement and test the software to get the connection between the locations up and running in a timely manner.

IVP Experiment Controller/IVP Controller (IEC/IC)

Purpose

During the research conducted in 2007, it became clear that it would be increasingly important to control all of the various configuration and experiment control elements through a single application, particularly as increasingly sophisticated experiments were planned for the IVP. Basically, it became essential to ensure that when a subject was in the IVP all of the environmental variables were correctly selected started and shut down synchronously and at the correct time during an experiment. While this could be done manually, doing so became less viable as the complexity of the environment increased, and the complexity and cost of the experiments being done increased. Fully documented and systems supported command and control functions would make the IVP more reliable, helping experienced users avoid mistakes, and also making it a more attractive experimental venue for less technically skilled managers or supervisors.

Shared Development

The IEC/IC was a major development effort within the program. Up to this point, the IVP had a limited controller to deal with the following complex processes:

- Configuring the technical environment, i.e. loading specific programs in a particular order
- Loading of the correct experimental control files and parameters, i.e. what subject, terrain, audio, AI, and treatments
- Managing the events to occur within that particular experiment and trial, i.e. starting and stopping movement, recording hits on targets, and creating the related data files
- Collecting data and messages during the course of an event, and
- Shutting down the IVP in an orderly fashion

The goal is to make the IVP more reliable and error free during experiment by providing a comprehensive, user-friendly, GUI based control capability. This will encourage experimenters to use the IVP with less training about the IVP. Specific development efforts included.

1. **GUI based IEC**

   As a result, the creation of a fully functional experiment controller was an early and major development goal of this program. This goal was not completely achieved. The requirements for an intuitive, GUI based IEC are included in the appendix, and a version of this was used to

manage the execution of Task 1 (Sphere Task) and Task 3 (Sniper Task), controlling the environments for the experiments and initiating and controlling its execution, including the collection of relevant data. Time and budgetary constraints prevented the extension of the GUI-based environment to support the full (two location) IVP needed for Task 3 (Teaming Task), so a command line controller, called the IC, was written, and used successfully. A goal of the next round of development of the IVP will be to complete the GUI-based application to provide the most reliable and error free environment for all users, but allowing less skilled or trained technical users to set up and run experiments.

2. Extracting information

Another major development activity had to do with the use of the IEC to execute experiments based on the **extraction of information from the environment** itself. For example, the design of Task 4 required the identification of suitable locations in the urban environments from which to attack a subject riding in a Humvee. For each subject and all subjects, these threats had to come from directions and elevations that fully tested the responses to different audio signals, so these had to be identified and selected in advance to get a correct distribution of locations and make sure that the sniper would be visible. To make the task of finding the sniper more challenging, the design called for ordinary civilians (distractors) to appear close to the sniper, so more locations had to be selected and tested before the experiment. In turn, this information was used by the IEC to activate a sniper and associated civilians at the correct point in the Humvee's movement through the urban environment. Being able to identify and reference specific locations is a crucial capability for experiments, particularly involving external participants, such as an airborne observer or UAV operator.

3. XML definition file

To support the operation of the IEC, the team also developed an **extensible XML-based file** to contain all of the configuration parameters for experiments. This provided an effective vehicle for the control and execution of sophisticated experiments. For example in the Sniper Task, the XML file contained information on the subject, the audio files to use, the start and stop locations for the trial, where and what targets and distractors would be presented to the subject, the time of day in the environment, along with other parameters. The advantages of using an XML file are that it is standardized and has an easy to edit structure and flexibility.

The requirements document for the IEC is included in the appendix to this report, as are samples of the XML file.

Task related development

Task 1

This was the first experiment in which the IEC was used to control the experiment and the treatments for the subjects. Although simpler than subsequent environments, it represented a significant improvement over previous versions of the IVP in terms of the control it provided for those managing the experiment and ensuring that the correct parameters and file sets were loaded prior to the execution of the experiment.

Task 4

The IEC was extended in Task 4 to include the input from the “scenario generator” and XML control file to manage the full set of activities for the vehicle convoy, including

- Moving from a defined starting point
- Detecting entrance into an attack area
- Stopping of the vehicle
- Presenting targets and distractors
- Communicating with the IVE about trial status

This was a very significant level of complexity to manage within the controller, but was nonetheless successfully implemented. As noted, additional development is needed to improve it's ease-of-use and reliability in terms of managing experiments.

Task 3

Time and funding made it impossible to extend the capabilities of the IEC to deal with two IVP environments at the same time. As result, a decision was made to develop the IC, a simpler, command line controller for this experiment that could be implemented within the contract period.

IVP Visual Environment (IVE)

Purpose

The IVE is an essential component for all experiments using virtual environments since it is what drives the visual experience in real time and in immersive stereo. It defines what subjects’ experience in the IVP, including their auditory and visual experience and interactions with the virtual environment. It brings together the rendered elements of the terrain, what subjects see, with tracking and interactive capabilities, to allow subjects to move, see and perform tasks within the environment and other entities (avatars) within it. As a result of the work done in the course of this program, it was also learned that the IVE has to deal with a portion of the data collection tasks to avoid latency problems and ensure synchronicity in data between environments that are physically separated. The principal tool used to develop the IVE was Vega Prime from Presagis.

Shared development

The following were key shared development efforts:

1. **Simulation of the ALF**

   The ALF is 4.3-m geodesic sphere with 277 Bose 11-cm full-range speaker drivers mounted its surface (see Figure 4). The sphere is housed in a large double-walled anechoic chamber. Custom-built high-power switching hardware (Winntech) can route up to 15 signals to any or all of the 277 speakers. Early in the program, the team decided to build a replica of this in the VERITAS environment to ensure that results for experiments being done in IVP could be tied to outcomes of research that had already been done in the ALF. A virtual environment comparable to the ALF was developed and the IEC programmed to simulate the visual search and other types of ALF activities.

2. **Expanded Urban Terrain**

   The IVE was modified to accommodate the use of much larger and more complicated urban terrains. In all previous IVP experiments, even one involving an observer in a loitering helicopter, the scale and flexibility of the terrain was limited. In addition, the experiments reported here the IVE had to handle more sophisticated interactions between the wand and the environment and support different motion models in the two environments. When the problem related to centralized data collection became evident, the IVE was enhanced to capture critical data within each environment on a local basis.

3. **Performance**

   Performance of the IVE is a critical issue because the active stereoscopic technology used in the IVP means that the environments must be rendered at a certain frame rate to create a realistic environment, avoiding distracting jerkiness in the motion as subjects seek out targets or move.

4. **Motion models**

   Work during the project also addressed the differences between the two environments of the IVP, i.e. VERITAS has 5 sides and the iSpace has 4 sides. This changes what subjects can do in some situations, for example, turnaround to see thing, the team created models that supported realistic movement in both, so that with training, the environmental differences were not an issue.

Task related development

Task 1

The major component here was the creation of the sphere environment, which replicated the ALF in terms of its physical appearance. In addition, the IVE ran events that were analogous to what was normally done in the ALF.

Task 4

The major development was to create a motion model involving a convoy of vehicles moving along a predetermined path through an urban terrain. This included a control element, forcing the subject to focus on a target on the back of the vehicle immediately ahead of them in the convoy, to make the convoy move and manage the orientation of a subject when they entered an ambush location. These locations were controlled to ensure that snipers appeared across a full range (azimuth and elevation) of locations throughout the course of the experiment, i.e. a subject would have to locate objects all around them and also in elevation from where they were to realize a reasonable distribution comparable across all subjects in the experiment. The IVE responded to commands from the IEC to start and stop following the predefined paths, load a file defining a path and pausing for trials. Another major development effort completed for this task was the addition of local data collection in the IVE. This allowed for collection of user inputs and the visual environmental status at the source without added latency.

Task 3

This experiment was the least constrained in that it involved dismounted subjects able to move freely through the urban environment. This is very different than the other tasks and more representative of the type of tasks that need to be performed going forward to evaluate potential technologies, like spatialized audio displays that could help PJs perform more effectively.

The IVE continued to use most of the elements developed in previous experiments including the introduction of hostile avatars. However, these now operated in a far larger terrain than was previously used. As a result, shooting interactions and other things had to be modified because the distances in the new "tiled" terrain were far greater. The walking motion model for the participants was updated to improve collision detection with other objects in the virtual world and add support for foot pedals as an input device in the iSpace.

Unlike the VERITAS facility in which a subject is completely enclosed in the simulation, the AVL has an open back wall that necessitated a slightly different system of moving throughout the virtual environment. Because the subjects could not physically turn to face

the rear of the room, they used a foot pedal system that allowed their avatar to turn in the virtual environment while the participant remained stationary. This allowed them to explore the entire environment while maintaining complete immersion.

The method for motion tracking differed by facility. In the VERITAS, a head tracker was employed, involving a small bar on top of the headphones, which was attached to a battery pack in the vest. At the AVL, however, head tracking was done by (equipment name) cameras in the iSpace, which cued off of reflective balls attached around the 3-D shutter glasses.

IVP Audio Environment (IAE)

Purpose

This component of the architecture supports the audio environment that subjects experienced during the course of an experiment. This included person-to-person communications and/or signals received from a command center or server or in the case of Task 1 simulating various speaker locations within the simulated ALF environment and its virtual replica. This is the part of the architecture that supports the spatialization of incoming audio signals so that they are rendered to come from the correct location within the virtual environment. The 3D models and data were combined with simulation positions to update the spatialization in real time. That is, sounds always appeared to arise from the designated location in "world coordinates" and did not appear to move when the participants moved their heads
The IAE was updated to manage and deliver an improved quality of signal through the implementation of a facility called "DIS radios". Given the goal of the program, the IAE is the critical component and was the focus of the early verification work in Task 1.1.

Shared development

The program took advantage of work that had been done and/or was ongoing in other RHCB supported projects. The core of the spatializing audio software is an open source application from NASA, called slab3d. Other development programs by RHCB incorporated this software into modules that could be used within the IVP to deliver high quality audio.

To support the use of DIS radios, the team had to convert the IVP from a HLA environment to a homogeneous DIS based system. This transition was challenging and created a number of technical hurdles that slowed the completion of the technical work for the experiments. New messaging types were needed along with the installation of DIS routers, all off which required comprehensive testing The team appreciates the efforts by John Stewart and the support from Dr. Brian Simpson for making this intellectual property available. Similarly, the team thanks Dr. Vic Finomore for providing access to some DIS compatible software that enabled recording of communications for subsequent semantic analysis.
An interactive series of physical analyses and psychophysical measurements in Task 1.1 aided in the integration and debugging of the IAE, slab3d, and DIS radio system. In addition, controls were

integrated into the IEC to verify that the audio parameters were set correctly.

In addition to supporting person-to-person voice communications, the IAE supported the delivery of different sound streams. For Task 3, the technical team had to define and develop an audio display linked to the “push to talk” control capability that allowed an individual to do two things with their voice.

1. Localize their own voice so when they spoke their partner would be able to determine where they were speaking from in the environment (i.e., their voice sounded like it was coming from the direction of their location). During the design of an earlier experiment, PJs commented that maintaining an accurate sense of where their team members were was a real problem. Task 3, which was done on a one-to-one basis, only, was the initial attempt to assess the potential for spatialized audio to help with this problem.
2. Annotate or attach their voice or an audio “tag” to an individual, location, or object in the environment, so that another team member would hear it coming from the location of the tagged object. This amounts to “audio pointing” and was assessed in Task 3.

The challenge was to create an audio display in which there was a readily perceptible difference between the two signal type so that an individual would be able to discern what they were hearing and its meaning, i.e. hearing a team mate’s voice where he/she was versus his/her voice associated with an object, such as a landmark in the environment. This capability was developed and implemented.

Task related development

Task 1

Subtask 1.1 used the ALF simulation to evaluate the effectiveness of the audio environment at the physical level plus procedures to make sure that individual HRTFs were correctly recorded and loaded.

Task 4

There were no major changes in the IAE for this experiment, but sound files had to be created for every single location of a threat in 3 different conditions requiring two different files:

- Spatialized audio,
- Semantic audio, i.e. a description of where a particular threat was located–it was time-consuming and complex to develop reasonable descriptions of where snipers were. For example, what is the best way to say that the sniper is in the 3rd building over on the 4th floor? However, this was necessary to create a baseline against which to assess the relative efficacy of spatialized audio, and

- Mono files that they were consistent in terms of the presentation of information, i.e. a voice saying “Sniper.”

Task 3

Task 3 involved the full implementation of DIS radios plus software to handle multichannel communications with voice to text translation. The audio display was implemented to differentiate between localizing a person and supporting annotation. It should be pointed out that this annotation capability will become a crucial element in experiments dealing with the integration of command-and-control capabilities or observers using other platforms over the environment such as UAV specialists. When they identify threats or other concerns, annotation may let them improve how they can effectively bring this information to the attention of troops on the ground.

The IAE had to operate across the two environments of the full IVP. Making sure that the network conductivity and latency could be managed so that there were not any overly long delays in the dialog between subjects that would feel unnatural.

For Task 3, the IAE recorded the conversations between subjects. Given the scale of the experiment, this provided a large base of data that will be used in future work to understand the effect of the different communication modes, spatial versus mono, in terms of the semantic content of the communications. This analysis could provide important insights into the effectiveness of the different audio modalities; mono versus spatialized, in terms of its effect on the nature of the dialogue between subjects. This could provide the basis for defining protocols
that could be invoked when using spatialized audio.

IVP Data Base (IDB)

Purpose

Conducting experiments in the IVP generates a tremendous amount of data, much of it very low level in nature, such as time and head position, and a very high frequency of collection (i.e. at frame rates (25-50 Hz) or cycle to cycle on a processor). The IDB has to provide a database structure that can deal with the volume and speed of the data, capture it on a timely basis, perform additional manipulations, and support extensive subsequent analysis to interpret the data. There was not adequate time or funding to build an IDB with these capabilities. As previously noted, a distributed approach proved necessary with some data being collected locally in the IVE and other centrally in the IEC.
In addition, the IDB must also capture and manage the various DIS messages being sent within the environment. A commercial application from Mak Technologies, the Data Logger, was used to do this and it supports the ability to re-create events that have taken place within the IVP based on the associated DIS messages.

Technical development

Early in the program, the team recognized that the management of data will ultimately become the most significant component in realizing value from the use of virtual environments, like the IVP to support assessments of technologies to improve human and mission performance. During the program, a great deal was learned about the requirements for an effective IDB architecture and implementation, but no substantive technical development was completed in this area because of the other demands on time and resources. The following reflect some of what was learned.

1. **Volume of data**

   The IVP generates significant volumes of data because of the rate at which data are collected, frame-to-frame and/or processor cycle to cycle if necessary, and the diversity of that data. Further, it was essential that the collection of these data took place without impinging on the real-time execution of the visual and audio environments and any other interactions that were going on including movement, shooting etc.
2. **Decentralized collection**

   To complete the various tasks, some of the data recording was implemented locally at the data collection site and was not transmitted to a central storage site, as originally planed. However, as bandwidth increases and latency diminishes, it may be possible to use a centralized repository. This would eliminate difficulties that arise when collecting data in individual environments, including the synchronization of data and its consolidation for the analytic purposes.
3. **Analytical complexity**

   It also became clear that the subsequent analytics were not trivial in terms of the calculations that needed to be made. A comprehensive IDB approach would define how the raw low-level data would be used to create a derivative set of data that could then be used for analysis, whether that is related to the semantics of voice communication or around physical interactions and events.

   One example of the complexity of data is trying to answer the simple question of whether or not two individuals can see each other and/or some 3rd object in the virtual environment. Being able to do this in a real time manner makes the use of virtual environments very compelling for evaluation and training, certainly with respect to the effect of technologies on enhancing situational awareness.

Task related development

Task 4

Task 4 made it clear that data collection across the network was going to be problematic and that there was a need to provide some level of the data collection in each location to maintain the necessary synchronicity and not slow down the entire environment. As a result,

the initial design of having all of the data collected in the IEC was changed to have most data collected locally in the IVE.

Task 3

Data collection for this experiment was very different due to the freedom the subject had in moving through the environment and the quantity of audio data that was collected. Understanding how spatialized audio affected the search process will require more complex analyses of the data, including audio files. The data also dealt with shooter interactions with hostile entities in the environment keeping track of the number of times individual PJs/rescuers were hit. This is important because an objective for a PJ/rescuer is to avoid getting injured and thereby needing to be rescued.

Terrain

Purpose

This defines the physical aspects of the IVP environment in which the experiments occur, including buildings, doors, windows, roadways, vegetation, and their features. All of these were built using the Presagis' Creator application that provides a suite of tools to create objects that can be rendered in three dimensions. This application was the one used to create the simulated ALF sphere used in Task 1 and the urban terrains used in Task 3 and 4.

Shared development

1. **Terrain tiles**

   The terrain used in previous experiments was limited in terms of its physical dimensions (virtual) and of the variation that it offered for the execution of complicated experiments that required subjects to experience multiple trials in novel environments. Some of those limitations and constraints were driven by the nature of the hardware but it became clear from the earlier helicopter experiment that a more sophisticated approach was needed. Borrowing from some board games, the WSARC team proposed that terrain be developed in "tiles." These "tiles" could then be put together so that any edge in one could be matched up with the edge of another, regardless of orientation. Using different "tiles" in different orientations, a large number of varying terrains could be created. This approach was adopted and based on a standard .25 by .25 kilometer "tile." The work represented a very innovative use of the Creator environment. Despite this, the development effort to build six tiles complete with various types and configurations of housing and urban scenery was completed in three months thanks to the dedicated efforts of Andy Giese, a summer intern from the University of Dayton and Chris Mayhew, an intern working with RHCB. The six "tiles" were used to create a number of different terrains and their processing was optimized to sustain the necessary frame rate to maintain an acceptable visual environment.

2. Object Hierarchy

A key requirement that was not understood at the beginning of the development was the need to decompose the hierarchies within the building elements so that things like doors and windows could be uniquely identified. This became important during the development of Task 4 it became necessary to understand what windows, doors or other features a subject could see from their location in the terrain. As a result, this detail was added to the Creator files, a task that was both tedious and time consuming, but a valuable lesson learned.

By adding these elements to the terrain definitions, it became possible to extract the data for the locations of all components to develop experimental scenarios that insured two things:

- that the individual at a location could see the target, and
- that over the experiment the targets were presented with the necessary variety of azimuth and elevation to fully evaluate the effect of spatialized audio versus other means of communication

3. Scenario Generator

Two programs were developed to support this design requirement. The first was an extraction routine to query the terrain database and extract information on the location of all visible locations from a subject location. The second reviewed these extracted locations and selected the ones to be used by a sniper so that the necessary distribution of azimuth and elevation was achieved. Given the scope of Task 4 to locate 1,620 such locations, it would not have been possible to select sniper locations manually, let alone populate other locations with ordinary civilians to distract the subject. More importantly, this development creates the future possibility of a coordinate as opposed to entity-based system for defining interactions within the IVP. This approach is more in line with the integration of sensor information into the environment and its communication from external command centers or UAV operators.

4. Pathing

Another enhancement to the terrains was to develop the concept of "pathing" through the environment, defining the starts and ends, and stopping points (ambush locations) along the way. This was done for Task 4 so that the route traveled was controlled to ensure the desired distribution of targets in space. This capability was also used in Task 3 looking at different points to start individuals from as they were searching for someone else.

Task related development

Task 4

This task was the first to use the “tiles” for the terrain with the extended hierarchy to include doors and windows. Completing this work did delay the execution of the experiment by over 2 months. In the course of running the experiment, the use of the “tiles” proved to be very effective and allowed the team to create a large number of terrains; thereby reducing the likelihood of the subjects learning about the terrain they were in. The process to generate new 2X2 “tiles” became routine, mixing and matching the different individual “tiles” to create new integrated terrains as required.

With 6 tiles, the number of possible combinations is very large given that any side can be abutted to any side, without additional development. Adding changes in elevation and other components to increase realism would be a useful extension for a future development activity and a small sub-project created interiors in a few buildings to demonstrate how an individual could move inside and move up and down stairs.

Task 3

The experiment took advantage of the “tiled” terrain, but required a far larger number of unique “tile” combinations. Again, this was done to avoid learning. Different starting points for searches were implemented and to evaluate the impact of landmarks on the task, terrains were created with and without landmarks using a toggling feature implemented within the “tiles.”

Artificial Intelligence (AI)

Purpose

The two aspects of using artificial intelligence components within the IVP are:

1. Dealing with the simulation of events based on other events and interactions so that certain actions unfold as the subject moves in the environment or interacts with it, and
2. Introducing digital entities in the environment that can be made to behave in certain ways depending on circumstances. For example, the use of AI might allow an entity to see a dismounted PJ and either approach to attack or run away and hide. These behaviors have become increasingly sophisticated.

The treatment element of the architecture defines values of the variables specified by the design of a particular experiment. These vary significantly based on the experimental scenarios and may include: time of day within the virtual environment, starting point within a terrain, location of waypoints, partnering teams, speed of movement, etc.

Shared development

All of the experiments required the execution of simulated events. In Task 1, these were the simulation or emulation of the normal localization tasks performed in the ALF. Task 3 integrated un-tethered movement by subjects through a terrain starting from different points and also meeting digital individuals (avatars) with certain types of preprogrammed behaviors for interacting with both PJ and the target subjects.

Task related development

Task 4

There was no significant AI component for this task.

Task 3

For this program, this task was the only one in which avatars with behaviors were included. Their behaviors were either passive, i.e. simply there as distractions, or as hostiles demonstrating those hostile intents by engaging in firefights with PJs or threatening the target subject to force him/her to keep moving. As a result, the AI for this experiment was more complex to support these interactions, but made easier because the subjects were able to move freely in the environment not through some preprogrammed set of pathways.

Team members in close proximity appeared to each other in the form of avatars. A direction indicator was present in the center of the base of all walls, displaying primary and secondary headings (N, NW, W, SW, etc.). Participants used a wand that projected a virtual line extending from the tip of the wand into infinity. This line functioned as a visual representation of the wand target.

Four thumb-accessible buttons on the wand allowed the participants to interact with the simulation environment. Of the other four buttons, one represented a push-to-talk function by which participants could communicate with one another in all conditions. The other three buttons pertained to the spatial audio condition discussed further below. An additional trigger functioned as a virtual gun for the PJs to use against enemies.

Treatments

Purpose

As mentioned the range of treatments possible within the IVP can be highly varied and controlled very precisely. These now include the ability to

- Mix and match different terrain “tiles”
- Execute from different starting points
- Follow different paths

- Run exercises at different times in the day
- Involve digital entities creating different interactions
- Engage different subjects and/or teams

These have to be defined and managed to support a particular experimental design. As a result, the creation of a system to define and manage the treatments down to blocks of experiments, to the teams within the blocks, and so on was another significant deliverable from the program. Ensuring that these elements came together appropriately was a very important aspect of the engagement between the researchers and the technical team.

Task related development

Task 4

Task 4 involved 6 subjects each moving through 9 different terrain each with 30 possible locations of which 10 were selected for each type of audio display; spatialized, semantic, and mono. It was a large experiment with a complex design in terms of the application of specific treatments. The development of the XML treatments file was essential to the successful execution of the project and its management. Without this and the IEC, it is unlikely this task would have been completed considering that for each of the 270 locations that a subject was exposed to required a calculation to make sure that they could see the target and that over the course of the trials for a particular audio treatment; spatial, semantic or monaural there was an even distribution in terms of azimuth and elevations. This is not trivial and required a great deal of effort to develop these files and then to test all of the locations in all of the terrains on all paths to make sure that they all functioned correctly, i.e. that the vehicle stopped at the appropriate point, that the targets presented themselves appropriately, and again that at the end of this experiment that an even distribution of locations was achieved.

Task 3

The treatments had to mitigate learning and also support the exploration of a number of different options with respect to the use of audio annotation (versus non-annotation) and of landmarks, based on where subjects started. Because the subjects were free to move anywhere to find each other, the treatments were constructed to create the maximum amount of flexibility and variation across the entire set of experiments. This approach would level out any differences in terrains, for example some terrains were more difficult to navigate and or certain hostile interactions were harder to deal with.

4.4 Results, Conclusions And Recommendations

This section documents the results of the technical development effort during the program, the conclusions or “lessons learned” from that work, and the recommendation for future priorities and/or directions. There will be a similar section for each of the task write-ups and one for the overall program.

Results

There were three key results from the technical development activities completed in the course of the program.

1. Implementation of significant enhancement to IVP

a. Transition to an all DIS environment

This was done to ensure compatibility with other AF distributed simulations and virtual environments eliminating the HLA components and also to enhance the audio quality of the environment. The latter was through the implementation of DIS radios to generate audio sounds rather than Team Speak which limited the frequency range available, particularly at the higher ranges which are important for elevation discrimination. This conversion was time consuming, but the impact on audio quality was evident. As a result of the change, the installation of DIS routers to move message between the two IVP environments was necessary and also the development of special DIS message types replacing previously used HLA ones.

b. Development of experiment controller

In 2007, the recommendation was made to implement an experiment controller to manage the loading of configuration files for a particular experimental trial, the synchronization of the startup for all applications in one or both virtual environments, the execution of the trials themselves in terms of starting and stopping certain events or initiating activities within the trial, and the shutdown of the trial and the subsequent closing of all files and applications including any of data files used to collect information from the experiment. As noted, two different versions were deployed but these should be integrated and that is a recommendation going forward.

c. Implementation of Terrain “Tiles”

The technical team pioneered the development of terrain “tiles”, which could be manipulated to create a very wide variety of subject environments for experiments. In addition, the size of the terrain in which the experiments could take place was dramatically enhanced from a few hundred meters to .5 kilometers along the edges and close to three quarters of the kilometer on the diagonal. This supported experiments of much longer duration than was previously possible and as a result the introduction of more complex elements into each of the experimental design scenarios. In addition, the creation of hierarchies within the rendering software (Creator) provided the capability to do very detailed analysis on “field of view” and “line of sight” defining occlusions without the need to introduce additional entities. This capability will become particularly important as the IVP is further integrated with other systems such as command-and-control with ISR capabilities from UAVs, etc.

3. Development of three unique experimental environments

The virtual environments experienced by subjects in Tasks 1, 3 and 4 were dramatically different. Task 1 implemented a virtual analog to the ALF sphere environment including the ability to emulate the types of experiments conducted in that environment. Although Tasks 3 and 4 used the urban terrain developed using "tiles", the ways in which the subjects interacted with them were vastly different. In Task 4, the subject rode in a Humvee traveling in a convoy through the urban environment, and in the other the subjects were able to move freely within the environment as they searched for each other

4. Development of compelling and highly usable experimental environments

The subjects used during the course of the various experiments were untrained in terms of the specific missions that they were asked to perform. They were also inexperienced in working in a virtual environment and using the interactive devices. It was found that with relatively little training, subjects were able to operate effectively in the technical environment, to move through a virtual space and to execute the assigned tasks. This is indicative of the real advantage of using virtual environments for not only the evaluation of technologies, but also the completion of education and training activities on an accelerated and very cost-effective basis.

Conclusions (Lessons Learned)

Despite the work that had been done using the IVP since 2007, a great deal was learned in the execution of this program in terms of the challenges of working in virtual environments and developing effective and meaningful experimental scenarios.

1. **Technical workload and resources**

The technical workload was underestimated. The experiments that were planned and conducted became increasingly complex and as a result the environment and all of the adjunct components became correspondingly complex. It is unlikely that these requirements will diminish for future experiments, rather the IVP will need additional, more sophisticated capabilities. It is also clear that the pool of individuals capable of performing this work is very limited and aggressive efforts must be made to expand it.

2. Level of technical readiness

The IVP was less reliable than expected at the time that the SOW was developed in concert with the WSU team. As noted, the results of the experiment conducted in later 2009 immediately prior to this program pointed to a need to significantly improve the quality of validation and verification procedures for the IVP. These are essential to ensure that the

environment is performing correctly in terms of the basic elements of hardware and software, particularly those related to the audio function, which was the focus of the experimental activities. As a result, a significant portion of the effort on Task 1 was devoted to full end-to- end verification and validation of the audio environment using the ALF facility to actually physically measure sounds and make sure that they correlated correctly to what was being heard in the virtual environment. Going forward it will become increasingly important to repeat these validation and verification procedures including the calibration of subject and their HRTF files to ensure that they are correct and are being loaded properly before any experiment is started.

3. Amount of testing

This was under-estimated, particularly what was required to ensure that the environment used for a particular experimental trial was performing correctly. Over above the normal testing of the hardware, software and communications, the technical team had to verify that all of the experimental sequences a subject would experience performed correctly. For example, if a subject had to start a particular exercise in a specific location in the environment, then the test had to be conducted to make sure that the subject in fact could start there and that the experience they had from that point forward was consistent with the design of the experiment. This meant testing all the possible combinations of treatments within a particular experiment and for Task 4 this involved the technical team reviewing over 1,000 individual combinations before subjects were permitted to use the environment.

4. Data management

The purpose of building the IVP was to conduct experiments and collect the detailed data to assess the performance of spatialized audio. This requires a sophisticated data collection capability and while some suitable intermediate solutions were found plus the use of the Mak Data Logger to replay scenarios, it became apparent that a more comprehensive scheme for the management of data within the IVP is a priority.

5. Adaptable environment

The IVP is a very compelling two location, virtual environment in which to conduct experiments to evaluate the effectiveness of audio display systems. However, it is also clear that it could be adapted to evaluate other types of technology simply by modifications to the various software elements.

6. Process management

The technical management processes need to be improved, starting with a more rigorous environment for software development, more effectively linking design and development to the experimental design. While designs were eventually developed that supported the

experiments to assess human performance and the effect of audio display technologies, the process for developing these was arduous. As expected, it was highly collaborative and iterative, but given that the ability to execute experiments is heavily dependent on the technical environment and development, better processes for eliciting the experimental needs and translating these into highly reliable applications needs to be implemented.

7. Creative solutions

The use of the terrain "tiles" is only one example of the creative technical solutions developed during the course of the program. Others include the IEC, the "scenario generator" and the ALF simulator. All of these will deliver continuing value in future experiments involving the IVP. For example, the "tile" based terrain supports a coordinate based view of the environment that will be extremely important as additional experiments may introduce components like helicopters or UAVs and communications become dependent on resolving questions about joint visibility in urban environments.

8. Performance

Overall, the IVP performed well. The processors being used have adequate horsepower for the nature of the trials that were undertaken and it is anticipated that this will be true for at least the next few years. The projection environments will be viable and work effectively for at least this long.

Recommendations

From a technical perspective there are there specific recommendations in terms of priorities for the next round of developments in the use of the IVP.

1. **Completion of IEC**

   Having a single, user friendly IEC to control the IVP and the execution of experiments execution is essential. The purpose of developing the IEC was to allow less technical users to set up the correct environments to run experiments and to be able to manage the operation of the IVP successfully during their research. There are currently two versions and these need to be merged into a single GUI-based design. This is critically important to improve access to the IVP as a virtual environment for conducting human performance related experiments and as such should be the first priority for the next round of technical development to be done on the system.

2. **Enhanced IDB**

   The current database is not adequate, particularly with the addition of audio files and more sophisticated team-based interactions with more entities involved. The Mak Data Logger,

which captures the DIS messaging is adequate to provide context but a far more sophisticated system for retrieving and analyzing experimental data will be needed as the IVP is used in the future.

3. Ambient noise

The audio environment (IAE) needs to be enhanced to introduce accurately spatialized ambient noise in the IVP. Task 2 in the SOW was to investigate this particular area but was not started because of the outstanding technical issues from previous research. However, from the work that was done, it is important to be able to understand and differentiate different types of noises within the environment. In fact, this will be essential if a spatialized audio capability is ever going to be delivered to the field. It is clear that PJs rely on their sense of hearing. Even if having spatialized audio displays significantly improves their performance in navigation, threat mitigation and situational awareness, it must not interfere with other audio inputs, such as the opening of a door, that they must also hear and respond to appropriately.

4. Terrain Enhancement

The implementation of the tiling concept significantly enhanced the functionality of the IVP and the ability to use it for more sophisticated experiments. The next round of investment should build on this by adding more complex topographies and allowing subjects to enter and move around in buildings.

5.0 SECTION 5: EXPERIMENTAL TASK REPORTS

5.1 Introduction

The following three sub-sections are the experimental reports primarily prepared by the WSU research team headed up by Dr. Gilkey as the Principal Investigator. The reports included for Tasks 3 and 4 are being submitted to a conference and so their format is consistent with those requirements. This seemed a more expedient and cost effective approach. The report for Task 1 follows a similar format, but is not intended for a conference or publication.

5.2 Section 5.2 Task 1: The Influence Of Listening Environment On Sound Localization

We can expect that the effectiveness of a 3D audio display will depend to a large degree on the ability of that display to render sounds that appear to arise from the intended spatial location. The goal of this study was to compare localization performance in the IVP to a “known” standard. Specifically, a number of studies have demonstrated that very good localization performance can be realized in the Auditory Localization Facility (ALF) of RHCB at WPAFB (e.g., Simpson, 2002, Simpson, 2012). There are at least three reasons to expect good localization of live sounds in this facility. First, ALF is housed in a large double-walled anechoic chamber and thus provides a very quiet listening environment. Second, the facility is able to produce high-fidelity, broad-bandwidth sounds (.2 to 14 khz). Third, speaker specific preprocessing of sounds ensures that the system response is flat and the same independent of speaker location.

Significantly, localization performance with virtual sounds presented through headphones with SLAB (Sound Lab, Wenzel, Miller, & Abel, 2000; Miller & Wenzel, 2002) when heard in ALF is nearly as good as when live sounds are presented from the loudspeakers (e.g., Simpson, 2002; Brungart, Romigh, & Simpson, 2011). Listeners report that virtual sounds are hard to distinguish from real sounds and appear to arise from the speakers themselves rather than the headphones.

Even though the physical sounds produced by SLAB should be identical whether they are presented in ALF, VERITAS, or some other listening environment, there are several reasons to expect the perception of those sounds to be particularly good in ALF. First, as mentioned, ALF is a very quiet listening environment. The ambient noise level in ALF is about 44 dBC, whereas the ambient noise level in VERITAS is about 66 dBC. Previous research (Good and Gilkey, 1996; Lorenzi, Gatehouse, & Lever,1999; Simpson, 2011) indicates that localization performance is severely impacted by noise, particularly with regard to front/back discrimination. Second, the head-related transfer functions (HRTFs, filters that reproduce the spectral and temporal modifications that occur for a live sound as it travels from a particular source location to the eardrums of a particular listener) that we use to generate virtual sounds with SLAB are recorded in ALF. To the degree that high-fidelity signal processing is maintained, the sounds that reach the listener’s ears for live and virtual presentations in ALF should be identical. That is, virtual stimuli should sound “just like” live stimuli. In contrast to the fairly anechoic listening environment of ALF, VERITAS is very reverberant, so live stimuli presented in VERITAS would sound quite different from the virtual stimuli. If subjects try to localize the virtual stimuli to the location that a similar sounding live stimulus could have come, we might expect to see much poorer localization performance. Third, Gilkey, Simpson, and Weisenberger (2001) showed that binaural recordings “sound better” when heard in the same location where the recordings were made. While this appears to be related to the acoustic mismatch described above, the visual mismatch also seems to be a factor. That is, it is as if the listener uses the visual scene to determine what the stimuli should “sound like” in that environment and judges them as less realistic when they sound different than expected. So, for a number of reasons we expected localization performance in VERITAS to be worse than in ALF. Task 1 was designed to measure that difference.

Method

Listeners. A total of 4 male and 1 female normal hearing listeners, ranging from 20-26 years of age, participated in the study. The listeners were part of the paid listener panel maintained by the Battlespace Acoustics Branch at Wright-Patterson Air Force Base. Invidualized HRTFs were recorded for each participant in the ALF, with corrections for the HD280 headphones used in this study.

Apparatus.

ALF. When in ALF the listeners straddled a bench with their head at the center of a 4.3-m geodesic sphere with 277 Bose 11-cm full-range speaker drivers mounted its surface (see Figure 4). The sphere is housed in a large double-walled anechoic chamber. Custom-built high-power switching hardware (Winntech) can route up to 15 signals to any or all of the 277 speakers. However, for this study all sounds where rendered at the appropriate speaker locations using Slab3d (version 6.0.1) An Intersense IS-900 tracking device monitors the position of the subject's head and of a handheld wand that is used as a response device (as described below). A cluster of LEDs is mounted in the center of each speaker, which can be used to provide cuing and feedback to the subject, as described below.

Figure 4. The Auditory Localization Facility at Wright-Patterson AFB.

VERITAS. When in VERITAS (see description in Section 4.2), the listeners sat in a swivel chair with their heads in the center of a visual simulation of the ALF sphere. The simulation consisted of 3D models of the speakers made to appear 11-cm in diameter at locations corresponding to the speakers in ALF (the struts of the ALF sphere were not rendered). Because VERITAS only has 4 walls and a floor and does not have a top projection surface, speaker locations above 45° elevation were

not rendered. Four red dots in the center of each simulated speaker mimicked the LEDs in the ALF sphere. They could be brightened and dimed under program control and were used to provide cuing and feedback (as described below). The IAE with Slab3d (version 6.5.0) was used to render sounds at the appropriate speaker locations. VERITAS' Intersense IS-900 tracking system monitored the position of the subject's head and of a handheld wand that was used as a response device (described below).

Procedure. The procedures used were similar to those used in numerous previous experiments conducted in ALF; however, some slight modifications were needed to accommodate the differences between ALF and VERITAS.

Stimuli. The target to be localized in ALF was a 250-ms burst of white noise that was square gated on and off and presented at approximately 60 dB SPL (measured at the center of the sphere with no listener present). In VERITAS, the target was a 100-ms white noise with 5-ms Blackman onset and offset ramps. Listeners were allowed to adjust the target to a comfortable listening level. The same set of speaker locations was used in both ALF and VERITAS. Because some speaker locations below -45° elevation are partially blocked by obstructions in ALF, speakers below -45° are typically not used. As mentioned, because there is no top screen in VERITAS it was not possible to visually render speaker locations above +45° elevation. Therefore, the speaker locations used in this study were restricted to the 200 speakers between -45° and +45° elevation. All sounds were virtual and slab3d was used to spatialize the sounds in both locations.

Trial sequence in ALF. In ALF, the subjects straddled a bench that was mounted on a platform in the center of the sphere. To begin each trial the subjects had to position their head in the center of the sphere and orient toward the speaker at 0° azimuth and 0° elevation; the LED cluster on that speaker indicated when this position was obtained. Once the LED cluster was lit, the subjects could press a button on the wand when they were ready for a trial to begin. The stimulus was then presented. After the stimulus was presented the subjects turned toward the perceived location of the sound and pointed with the wand at the speaker that they believed was in the direction of the sound. The speaker they were pointing to was indicated by illuminating the cluster of LEDs on that speaker. When the intended speaker was indicated, they pressed a button on the wand to register their response. After they responded, feedback was provided by illuminating the LED cluster on correct speaker. The subjects pressed a button to acknowledge the feedback and oriented to the front speaker to get ready for the next trial.

Trial sequence in VERITAS. The trial sequence in VERITAS was similar to that in ALF. However the subjects were seated in a chair that swiveled allowing them to turn to face any speaker. The head tracker indicated when the subject was oriented toward the virtual speaker at 0° azimuth and 0° elevation; the VERITAS ALF model included a small "F" under the 0° azimuth and 0° elevation speaker and "B" under the 180° azimuth and 0° elevation speaker to help avoid disorientation about which was the front or back speakers. As in ALF, once the correct position was obtained, the subjects could press a button on the wand to initiate a trial. After the stimulus was presented, they responded by pointing the wand at the desired speaker; the selected speaker was

indicated by brightening the “LEDs” on that speaker. When the intended speaker was selected, the subject pushed a button on the wand to register their response. After they responded, feedback was provided by brightening the LED cluster on correct speaker. The subjects pressed a button to acknowledge the feedback and oriented to the front speaker to get ready for the next trial.

Block structure. Data in both locations were collected in eight 50-trial blocks for each subject. Each of the 200 speaker locations was presented twice for a total of 400 trials per subject per location.

Results and Discussion

Initial psychophysical measurements obtained under this project were not as expected and provided the motivation for physical measurements of the stimuli presented at the two locations. These analyses revealed several hardware and software bugs in the slab3d implementation, the individualized HRTFs, the IAE implementation, and the physical measurement procedure.

The psychophysical results after addressing these problems are shown in Figures 5 to 9. Each figure shows the results for one of the five subjects. The top row in each figure shows the data from ALF and the bottom row shows the data from VERITAS. The data are plotted using the 3-pole coordinate system of Wightman and Kistler (1997). Each panel shows a scatter plot of the response coordinate as a function of the stimulus coordinate for the 400 individual trials. The left-hand panel in each row shows the Left/Right coordinates (the Left/Right coordinate of a location is the angle between a vector from the center of the head to that location and the median plane). The middle panel shows the Front/Back coordinates (the Front/Back coordinate of a location is the angle between a vector from the center of the head to that location and the frontal plane). The right-hand panel shows the Up/Down coordinates (the Up/Down coordinate of a location is the angle between a vector from the center of the head to that location and the horizontal plane). The rms error between the stimulus coordinate and the response coordinate is shown above each panel.

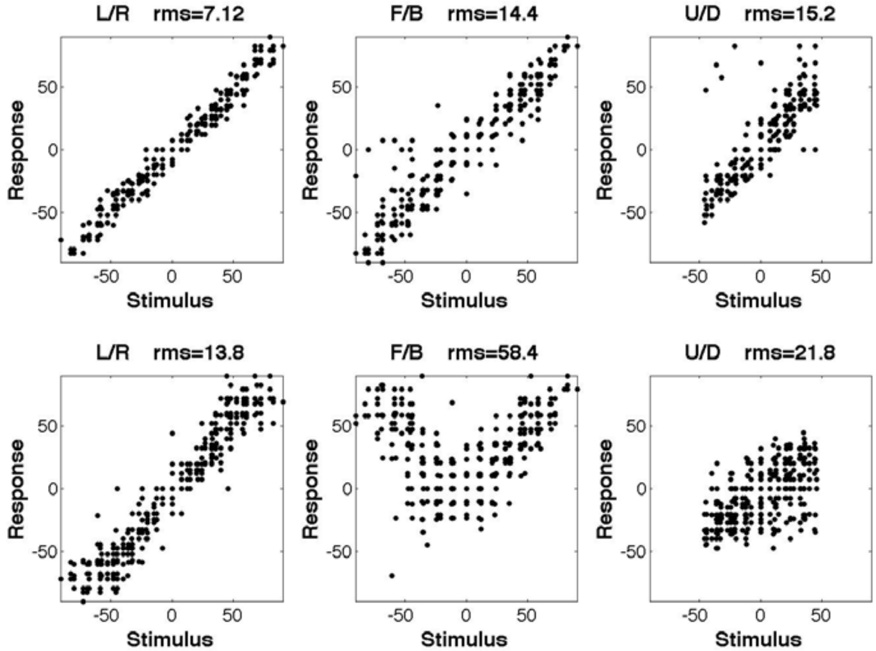


Figure 5. Results from ALF (top row) and VERITAS (bottom row) for Subject P1379. **Results from ALF (top row) and VERITAS (bottom row) for Subject P1379.** **In each row, left, middle, and right panels show the Left/Right, Front/back, and Up/Down coordinates, respectively. Within each panel, each data point shows the response coordinate for each individual trial plotted function of the coordinate of rendered stimulus on that trial.**

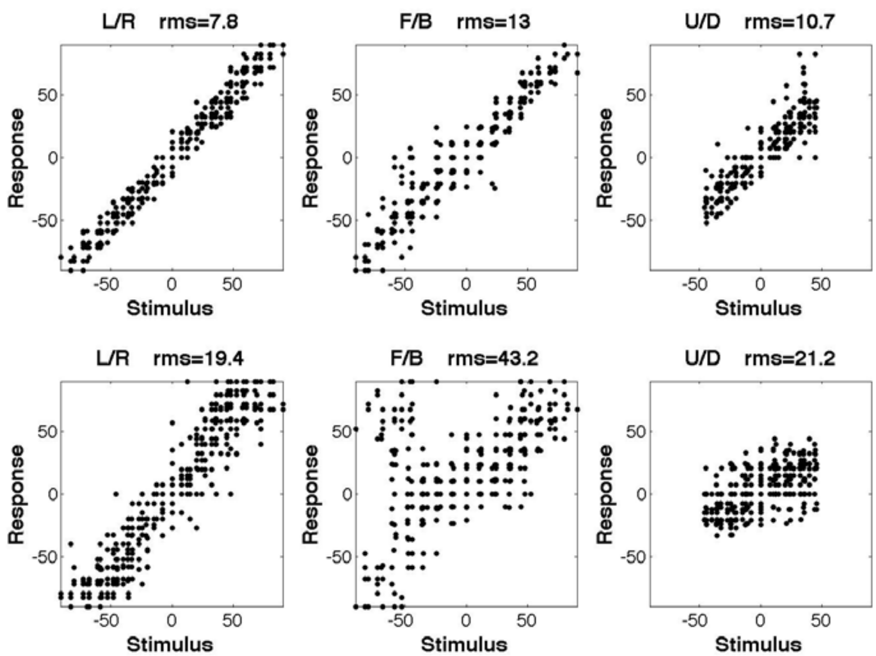


Figure 6. Results for Subject P1401 are plotted in the same manner as Figure 5.

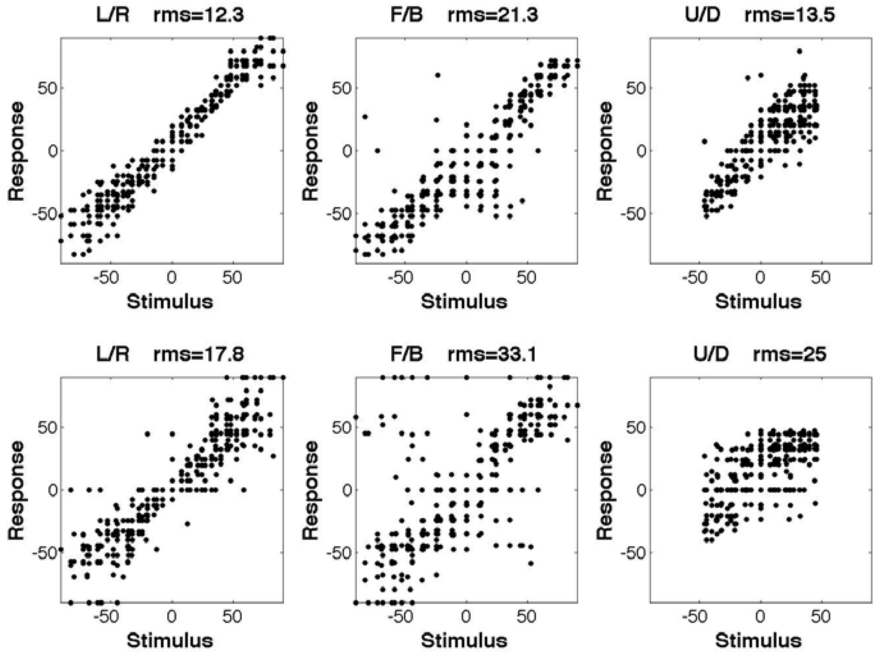


Figure 7. Results for Subject P1442 are plotted in the same manner as Figure 6.

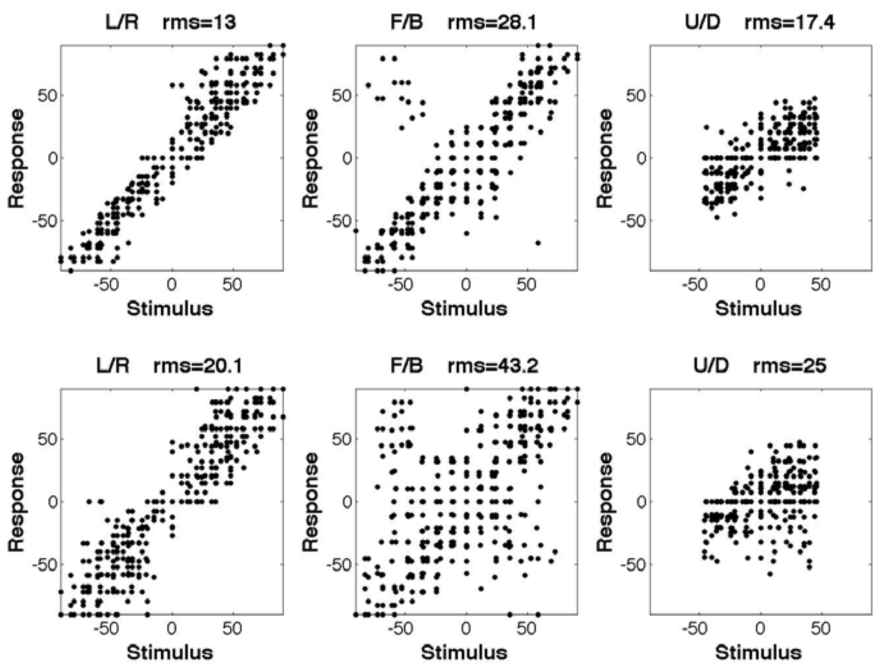


Figure 8. Results for Subject P1447 are plotted in the same manner as Figure 6.

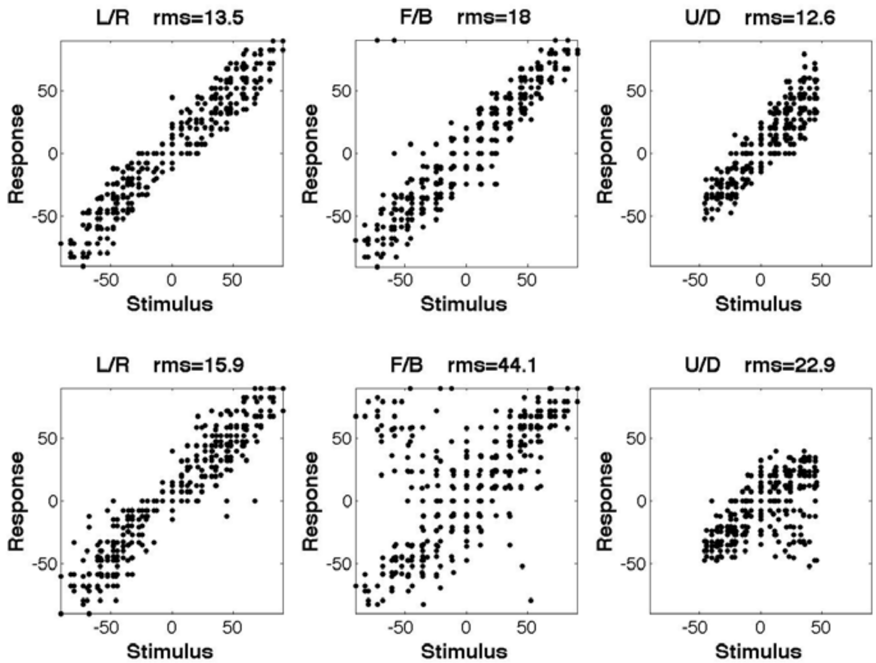


Figure 9. Results for Subject P1481 are plotted in the same manner as Figure 6.

As expected, localization judgments in VERITAS were less accurate than those in ALF. However, the magnitude of these differences was larger than we anticipated. In part, this is because performance in ALF was very good. Left/Right errors in ALF ranged from 7° to 14°. Although Left/Right errors in VERTAS were poorer, they were still fairly low 14° to 21°. On the other hand, Front/Back errors in VERITAS were much larger, exceeding 40° for most subjects. This is largely due to the substantial number of back to front reversals. Indeed for subject P1379 most sounds presented in the rear hemisphere were reported to be in the front hemisphere. The picture in the Up/Down dimension is less clear because of the limited range of elevations considered. That said, performance was substantially worse in VERITAS.

The reasons for the surprisingly poor performance in VERITAS are uncertain. As mention in the introduction, differences in ambient noise levels, reverberation, and/or visual environment could be the cause. It is also possible that the different versions of slab3d or differences in the duration, level, and/or temporal envelope of the stimuli between ALF and VEITAS could have contributed; but we would expect the impact of these differences to be small. Finally, it is possible that additional bugs in the IAE, slab3d or possibly the ALF software, could still be present. Limited time and funding did not allow for further examination of these issues. Clearly, additional effort is needed going forward to identify and resolve these questions.

References

Brungart, D.S., Romigh, G., & Simpson, B.D. (2011). Rapid collection of head related transfer functions and comparison to free-field listening. In Y. Suzuki, D. Brungart, Y. Iwaya, K. Lida, D. Cabrera, & H. Kato (Eds.), *Principles and applications of spatial hearing* (pp. 139-148). Singapore: World Scientific.

Gilkey, R. H., Simpson, B.D., & Weisenberger, J. M. (2001). Creating auditory presence. *Usability Evaluation and Interface design: Cognitive Engineering, Intelligent Agents, and Virtual Reality, Volume I of the Proceedings of HCI International 2001*, 609-613.

Good, M. D., & Gilkey, R. H. (1996). Sound localization in noise: I. Effects of signal-to-noise ratio. *Journal of the Acoustical Society of America, 99,* 1108-1117.

Lorenzi, C., Gatehouse, S., & Lever, C. (1999). Sound localization in noise in normal-hearing listeners*.* *Journal of the Acoustical Society of America, 105,* 1810-1820.

Simpson, B. D. (2002). *The localization of phantom auditory images* (Unpublished mater's thesis). Wright State University, Dayton, OH.

Simpson, B. D. (2011) *Sound localization in multisource environments: The role of stimulus onset asynchrony and spatial uncertainty* (Doctoral dissertation). Retrieved from www.ohiolink.edu/edt/

Miller, J.D. and Wenzel, E.M. (2002) Recent Developments in SLAB: A Software-Based System for Interactive Spatial Sound Synthesis. *Proceedings of the International Conference on Auditory Display, ICAD 2002*, Kyoto, Japan, pp. 403-408.

Wenzel, E.M., Miller, J.D., and Abel, J.S. (2000) A software-based system for interactive spatial sound synthesis. *Proceedings of the International Conference on Auditory Display, ICAD 2000*, Atlanta, GA, pp. 151-156.

Wightman, F. L. & Kistler, D. J. (1997). Factors affecting the relative salience of localization cues. In R, H, Gilkey & T, R, Anderson (Eds.) *Binaural and spatial hearing in real and virtual environments* (pp. 1-23). Mahwah, NJ: ErlBaum.

5.3 Section 5.3 Aurally Aided Visual Threat Acquisition

Eric Robinson[1], Brian Simpson[2], Victor Finomore[2], Jeffery Cowgill[1], Valerie L Shalin[1], Andrew Hampton[1],Thomas Moore[1], Terry Rapoch[3], & Robert Gilkey[1]
Wright State University[1];
Air Force Research Laboratory, Wright-Patterson AFB [2];
Wright State Applied Research Coorperation[3]

Many of today's military operations take place in large urban environment, which present unique challenges due to limited line of sight and increased concealment for enemy forces. This experiment evaluated the potential of a 3D audio display to aid threat detection and localization in a complex visual environment. Subjects rode as part of a convoy through a simulated city where they encountered snipers surrounded by distracting personnel. We compared 3D audio cues to verbal descriptions of the sniper's location and to simple audio warnings of the presence of a sniper. Consistent with past research, subjects located the sniper more quickly in the 3D audio condition compared to both the semantic description and simple warning conditions. The 3D audio display was faster than the other displays across all azimuths but, in contrast to previous findings, the advantage did not increase with increasing azimuth.

INTRODUCTION

Much of today's military operations are conducted by ground-based personnel carrying out missions in and around large urban environments. This new battlespace poses unique challenges to operators, as they are forced to fight among dense populations, where the distinctions between the appearance of enemy fighters and those who are friendly and/or neutral are less clear, and unintended consequences including collateral damage and fratricide are more likely to occur. Large structures can obscure the line-of-sight required to observe critical activities, and also provide convenient hiding places for snipers and other enemy forces. In addition, things change rapidly and unpredictably in these environments, and thus it is critical for operators to remain on high alert in order to maintain a sufficient level of situation awareness (SA).

In an environment where providing timely and unambiguous information can mean the difference between mission success and mission failure, it is critical that information displays are not only meaningful but, importantly, are attended to by the operator. The need for operators to remain hands-free and eyes-out, however, suggests that traditional approaches to information display, which tend to emphasize the presentation of information through the visual modality, may not be the most appropriate, for they require the operator's visual attention (thus reducing the time spent attending to events in the actual environment) and a transformation may need to take place when going from a 2-dimensional visual display to a 3-dimensional world. The use of advanced auditory display technologies, which can provide directional information indicating the location of threats in the immediate environment, can be an effective means of directing an operator's attention to specific locations in space. Such displays are intuitive, unambiguous, lead to rapid response times, and can be effective even when the operator is engaged in other concurrent activities (e.g., visually scanning the environment).

Ephrem, Finomore, Gilkey, Newton, Romigh, Simpson, Brungart, and Cowgill (2009) reported that subjects responded to threats more effectively when using a 3D audio display to cue threat location as compared to when using a monaural display. These results are compatible with more basic studies in the spatial hearing literature (e.g., Perrott, Cisneros, McKinley, & D'Angelo, 1996) demonstrating dramatic reductions in visual search times when a colocated auditory cue is available. However, in the experiment of Ephrem et al., the 3D audio display also provided navigation information. Potentially, the more effective navigation information allowed for extra time to monitor and address threats. Indeed, Gilkey, Simpson, Brungart, Cowgill, and Ephrem (2007) found that subjects were able to respond more rapidly and more effectively to threats when using a 3D audio navigation display that *did not* provide information about the threats. This experiment examined the effectiveness of 3D audio more directly in a single task scenario, by comparing 3D audio cuing of threat (a sniper) locations to a simple monaural warning without spatial information.

Typically, ground soldiers receive spatial information via verbal description. This can be time consuming and ambiguous, reducing mission effectiveness and potentially leading to loss of life. So, in this experiment the 3D audio display is also compared to a monaural warning that includes a semantic description of the threat location.

METHOD

To evaluate the effectiveness of 3D audio displays for cuing threat location, we developed a synthetic task in which the subject "rides," as part of a convoy, through a virtual environment depicting an urban terrain. During the ride, a number of threat situations arise and the subject must find and

neutralize these threats as rapidly as possible. Depending on the experimental condition, one of three displays alerts the subject to the threat.

Subjects

Six paid subjects (five male, one female) from the subject panel maintained by the Battlespace Acoustics Branch at Wright-Patterson Air Force Base participated in the experiment. They ranged in age from 21 to 26 years old, and had normal hearing and corrected to normal vision.

Apparatus

The experiments were conducted in the VERITAS facility; this facility is a room-size, 5-projection-surface (4 walls and a floor) virtual environment display system. High-resolution (1200x1200 pixel) stereoscopic images are rendered with Barco Galaxy NW-12 DLP projectors via RealD CrystalEyes shutter glasses. An Intersense 900 tracking system monitors the position of the head and handheld Wand. Sounds were spatialized using individualized head-related transfer functions with slab3d application (v6.5.0; Miller and Wenzel, 2002) and presented through Sennheiser HMD-280-XQ headsets.

Procedure

Terrains. Each block of 10 trials took place within one of nine virtual terrains, each measuring 500m x 500m. Each terrain was constructed from four of the six 250-m x 250-m "tiles." The tiles could be put together so that any edge in one could be matched up with the edge of another, regardless of orientation. Using different tiles in different orientations, a large number of varying terrains could be created. The tiles were created using Presagis Creator Pro software in Openflight. Each of the six tiles was used an equal number of times in constructing the nine terrains, but the location and orientation of the tiles was not controlled systematically.

The terrains contained varying numbers and types of structures, ranging from windowless one-story sheds to large five-story structures with many windows (a screen shot showing a representative scene is provided in Fig. 10). A loop was identified through each terrain, along which the convoy would travel (an aerial view of one terrain and loop is shown in Fig. 11). A total of 30 locations on each loop were selected as potential sniper-event sites; these sites tended to be surrounded by buildings with windows in most directions.

Figure 10. Screen shot of a representative terrain from the subject's viewpoint. The front and side walls of VERITAS are shown in perspective.

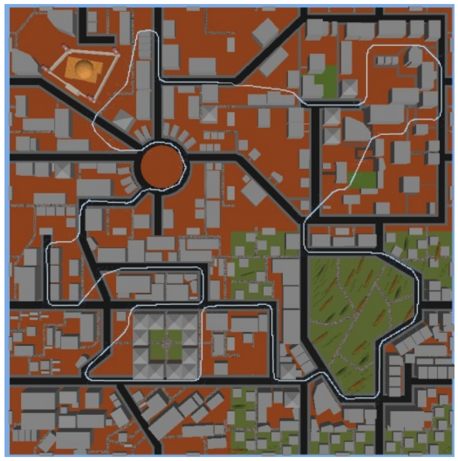


Figure 11. An aerial view of one of the nine 500-m by 500-m terrains, with the path traversed by the convoy during a block of trials shown by the white line.

Each terrain was used for one block under each of the three audio warning conditions. That is, each subject saw each terrain three times during the course of the experiment. We were concerned that subjects would learn the terrains and thus be able to anticipate when a sniper event might occur. In order to reduce the impact of such learning effects, the subjects experienced the terrains at three different times of day (dawn, noon, and dusk). These different times of day resulted in different lighting levels, which affected shadows and slightly altered colors in the environment. In addition, only 10 of the 30 potential sniper-event sites were used for a given audio warning condition, so that subjects experienced different actual sniper-event sites under different audio warning conditions. Finally, subjects started at different points on the looped path each time they experienced a terrain.

Task. During each block of 10 trials, the subject moved through one of the 9 terrains as part of a convoy of two Humvees. The subject was located on the rear Humvee. In order to make the convoy move, the subject had to orient her/his head such that a cursor, linked to the head tracker, remained positioned within a green target box on the lead Humvee (the green target box can be seen on the top on the lead Humvee in Figure 10). This ensured the subject's head was in a relatively constant position when they entered a sniper event site.

When the convoy entered an actual sniper-event site (initiating a trial), the convoy stopped, the head-linked cursor disappeared, exactly one sniper and a number of distracters appeared in the windows of buildings surrounding the convoy, and one of the three types (depending on condition) of auditory warnings sounded. Typically, the number of distracters was 50, but ranged from 10 to 50 depending on the windows available at any given site (M = 43.6 distracters). The sniper looked like an insurgent, and the distracters looked like US military personnel (see Figure 12). Subjects were instructed to locate and shoot the sniper (by pointing a hand-held wand and pulling a trigger) as rapidly as possible without shooting any US soldiers (a screen shot of the subject's view at the beginning of a representative trial is shown in Fig. 13). The convoy would not move on to the next trial unless the sniper had been shot. When the sniper was shot, the audio cue stopped and the images in the windows disappeared. The head tracked cursor reappeared and the convoy would continue along the path when the subject placed the cursor in the target box on the lead Humvee.

Figure 12. Image of the target (Left) and distracters (Right).

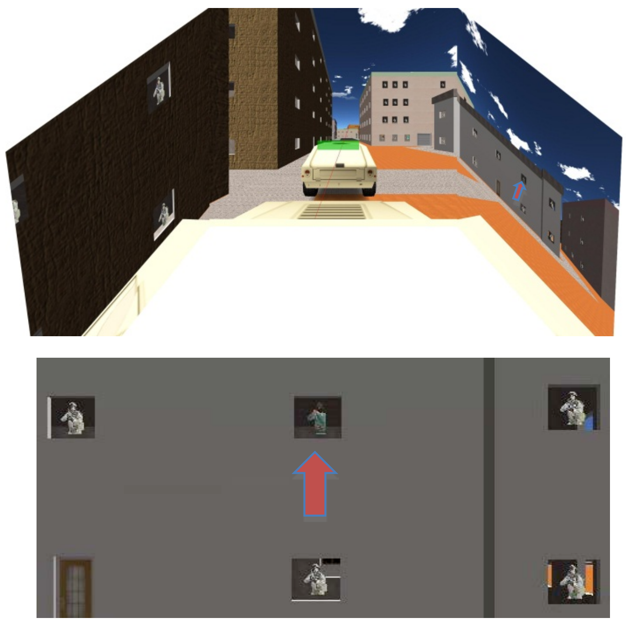


Figure 13. (Top) Screen shot of the subject's view at the beginning of a trial. The front and side walls of VERITAS are shown in perspective. For the reader, a red arrow has been added, indicating the location of the sniper. The distracters, dressed as U.S. service personnel, appear in many of the other windows. The same scene is depicted, an instant earlier, in Figure 10 (i.e., immediately before the trial began). (Bottom) Close up of the image in Panel a, without perspective; the location of the sniper is again indicated by the red arrow.

Audio Stimuli. Subjects experienced three audio conditions: monaural, semantic, and 3D audio. The monaural condition did not utilize any spatial or descriptive information. The monaural audio cue served simply to alert the subject that a trial had begun. The cue consisted of a train of three 50-ms bursts of white noise, separated by 25-ms of silence, followed after 25 ms by a recorded warning (a male voice saying "Sniper") and then by 500-ms of silence. This entire sequence was repeated until the sniper had been shot.

During the semantic condition, the cue was a pre-recorded verbal description of the sniper's location read by a male talker. These descriptions identified the building and window where the sniper was located. For example, the description for the trial depicted in Figure 13 was:

"Sniper. In the 2 story gray building on the second floor, second window from the right."

(Note, the target, and the distracters, could appear anywhere surrounding the subject in azimuth, but a frontal target location is shown here for clarity.) When the building was not readily distinguished from other buildings in the vicinity, the descriptions followed a basic heuristic of identifying a prominent feature in the environment visible to the subject and then using that as a reference to guide the subject to the sniper's location. For example:

"Sniper. There's a group of 4 buildings with blue bottoms, in the second building from the right, on the second floor, in the middle."

The duration of these recorded descriptions ranged from 2.0 to 7.0 s (M=4.1 s, SD=0.97 s). The descriptions were followed by 1.5 s of silence and then the sequence repeated until the sniper had been shot.

The cue in the 3D audio condition conveyed information about both the sniper's azimuth and elevation using directional audio cues. The source stimulus was identical to that used in the monaural condition, but was spatialized to be colocated with the sniper using slab3D.

Design. This study used a repeated measures design with audio condition as the primary independent variable. The presentation order of audio conditions was counterbalanced across subjects. Stimulus terrain, time of day, and path entry point were intentionally confounded with order (these nuisance variables are collectively referred to as "time of day"). In other words, each subject experienced the same presentation order of the combinations of terrain, time of day, and path entry point, but these combinations were paired with different audio conditions across subjects.

Trial blocks. One subject participated at a time. The experimenter read the subject the instructions for the task and audio condition and answered any questions. Once the subject received task instructions, the subject donned the vest that contained the wireless audio receiver/transmitter and put on the headphones (with the head tracker attached to the headband) and shutter glasses. The subjects sat in a chair in the center of the CAVE and held the wand.

Each block of 10 trials lasted approximately 10 minutes. Subjects experienced all nine terrains within each audio condition, one block per terrain. Each block contained only one type of audio cue, and all nine blocks for a given condition were completed before the next audio condition was introduced.

Subjects received one training block of 10 trials at the start of each new audio condition. Sessions lasted one hour, with a several minute break approximately half way through the session. When subjects required more than one session to complete an audio condition, they received a refresher block of three trials to reacquaint them with the task at the start of each subsequent session. After the training/refresher block, subjects experienced the trial blocks for that audio warning condition.

RESULTS AND DISCUSSION

We replaced outlier trials that were more than 3 SD from the mean for that particular block and subject, with the average of the remaining trials for that block and subject.

To evaluate the resulting 1,620 data points, we used a repeated measures ANOVA with 3 levels of audio warning * 3 times of day * 10 trials, and tested all effects with treatment-specific participant * treatment interactions. Audio condition did not interact with the nuisance variables: time-of-day or trial. The ANOVA indicated a significant main effect for audio condition ($F(2,10) = 9.07$, $p < .0057$, 3D Audio: *M*= 6.61 s, *SD*=6.45 s, Semantic: *M*= 9.19 s, *SD=6.57 s*, Monaural: *M*= 11.474 s, *SD*=10.12 s (see Figure 14). This F ratio remains significant when evaluated with the Geisser-Greenhouse correction, $F_{critical}(1,5) = 6.61$, a = .05, and all paired comparisons are significant at a = .05 with a t-test and error terms specific to the means in question (monaural vs. semantic, $t(540)=4.40$; semantic vs. 3D audio, $t(540) = 6.50$; and monaural vs. 3D audio, $t(540) =9.41$). Time-of-day effects are significant, most likely indicating a practice effect $F(2,10) = 7.60$, $p < .0098$, *M(morning)*= 10.134 s, *M(noon)*= 8.711 s, *M(afternoon)* = 8.425 s.

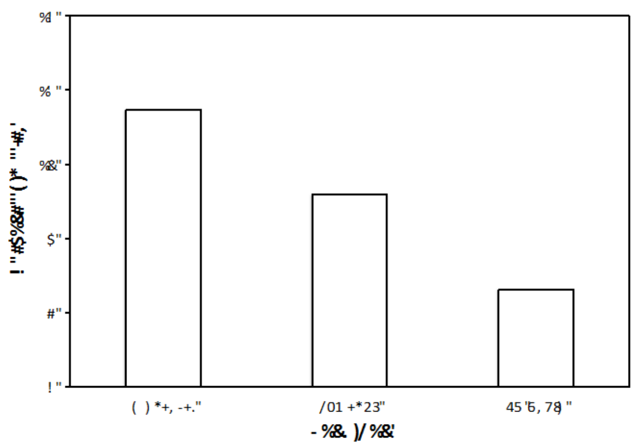


Figure 14. Time to acquire and neutralize the sniper under each of the three audio warning conditions.

These findings replicate and extend previous results that demonstrated dramatic reductions in visual search times when spatialized auditory cues are provided (e.g., Perrot et al., 1996; Simpson, Brungart, Gilkey, Cowgill, Dallman, Green, Youngblood, and Moore, 2004). Simpson et al. found that their 3D audio display led to more rapid responding than simple clock angles. Importantly, we also found advantages for 3D audio when compared to warnings that provided detailed semantic descriptions of the sniper's location; these semantic descriptions were like what ground soldiers might actually encounter in operational settings.

Figure 15 shows response time as a function of the absolute value of the sniper azimuth relative to the initial orientation of the subject's head. As expected and in agreement with the previous literature, response times generally increase with azimuth (e.g., Perrott et al.; Simpson et al.). However, in contrast to previous findings, although responses are more rapid with the 3D audio display at all azimuths, this advantage does not increase systematically with increasing azimuth. It is not immediately clear why this should be the case. One explanation maybe the relatively poor front/back discrimination

observed in Task 1 when the sounds were presented in VERITAS (however, this finding also does not have a clear explanation).

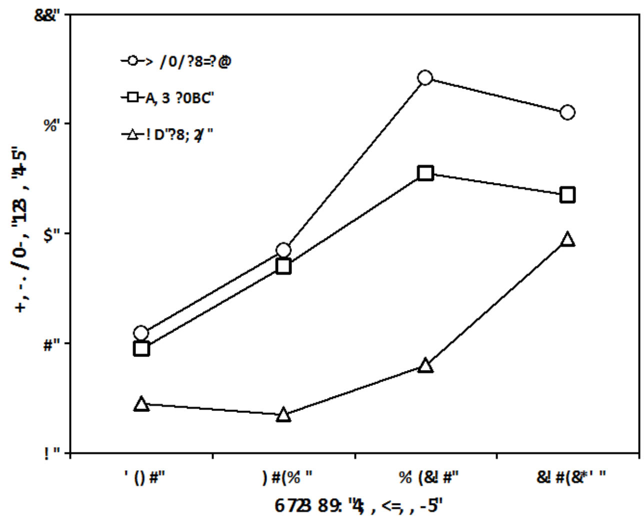


Figure 15. Mean length of time to acquire and neutralize the sniper as a function of the head-relative sniper azimuth under each of the three audio warning conditions. Positive and negative azimuths have been combined.

Overall, these findings are encouraging and provide further evidence for the potential utility of auditory displays in operational settings. That said, the somewhat counter-intuitive results as a function of azimuth, need to be more fully explored and understood in order to determine how best to implement and deploy this technology. For example, perhaps another cue (e.g., pitch, timbre) could be used to supplement front/back cues. Or perhaps semantic and spatial displays should be combined.

REFERENCES

Ephrem, A. J., Finomore, V. S., Gilkey, R. H., Newton, R. M., Romigh, G. D., Simpson, B. D., Brungart, D. S., & Cowgill, J. L. (2008). An “Audio Annotation” technique for intuitive communication in spatial tasks. In *Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting, 52,* 2127-2131.

Gilkey, R. H., Simpson, B. D., Brungart, D. L., Cowgill, J. L., and Ephrem, A. J. (2007). 3D Audio Display For Pararescue Jumpers. *Proceedings of the HFES 51st Annual Meeting, 51,* 1349-1352.

Miller, J.D. and Wenzel, E.M. (2002) Recent Developments in SLAB: A Software-Based System for Interactive Spatial Sound Synthesis. *Proceedings of the International Conference on Auditory Display, ICAD 2002*, Kyoto, Japan, pp. 403-408.

Perrott, D.R., Cisneros, J., McKinley, R.L., & D'Angelo, W.R. (1996) Aurally aided visual search under virtual and free-field listening conditions. *Human Factors*, 38, 702-715.

Simpson, B.D., Brungart, D.S., Gilkey. R.H.,
Cowgill, R.l., Dallman, R.C., Green, R.F., Youngblood, K.L., and Moore. T.J. (2004). 3D audio cueing for target identification in a simulated flight task. *Proceedings of the Human Factors and Ergonomics Society 48th Meeting, 48,* 1686-1690.

5.4 Section 5.4 The Impact of Spatialized Communications on Team Navigation

Andrew Hampton[1], Valerie L. Shalin[1], Eric Robinson[1], Brian Simpson[2], Victor Finomore[2], Jeffery Cowgill[1], Thomas Moore[1], Terry Rapoch[3], & Robert Gilkey[1]
Wright State University[1];
Air Force Research Laboratory, Wright-Patterson AFB [2];
Wright State Applied Research Coorperation[3]

This task examined possible roles for a 3D audio display in a team navigation task. We considered two specific capabilities: 1) spatializing a communication channel so that the receiver hears the talker's voice as arising from the actual direction of the talker and 2) spatializing a communication channel so that the receiver hears the talker's voice as arising from the direction of an object (such as a landmark) that the talker has "marked" with a laser rangefinder. Several lines of research suggest that the ability to point physically or semantically to specific locations or destinations in an environment (indexicality) facilitates the exchange of verbal directions for navigation. The person receiving the directions can rely on relatively automatic perceptual-motor processes to aid the comprehension of ambiguous, and inherently incomplete symbolic representations of spatial information (A. Clark, 1999; Green & Hummel, 2004). When both subjects in a conversation can access a common referent, the shared access establishes common terminology (Brennan & Clark, 1996) and the referents for pronouns and other ambiguous terms (Clark & Wilkes-Gibbs, 1986). In so doing, subjects can monitor their own comprehension by detecting and correcting misapprehension (Richardson & Dale, 2005). Moreover, the talker can simplify the directions and thereby reduce both parties' workload (Daniel & Denis, 2004). Thus, the speaker avoids formulating complicated spatial transformations required to assist reasoning from the recipient's perspective (Newcombe & Huttenlocher, 2000) or otherwise risk adding to the recipient's cognitive demand (Hanna, Tanenhaus & Trueswell, 2003). So, for all of these reasons, the ability to identify unambiguously locations in a large-scale spatial environment should benefit the coordinated navigation of spatially disparate teams. The 3D audio display we consider identifies the location of the talker (capability 1) or identifies the location of an important feature in the environment (capability 2) and thus should lead to both improved navigation performance and systematic changes in language use.

Much of the available research on collaborative spatial reasoning provides a visual foundation for shared access to the experimental stimuli, and has only used experimental paradigms that utilize small-scale stimuli, such as maps, blueprints, circuit boards or jigsaw puzzles (e.g., Velichokovsky, 1995). Further, such research sometimes confounds two conceptually separable pathways for monitoring partner comprehension: 1) eye-contact between subjects and 2) gaze awareness, that is awareness of where one's partner is looking. Later research specifically identifies the advantage of shared visual access as gaze awareness (Monk & Gale, 2002; Brennan, Chen, Dickenson, Neider & Zelinsky, 2008), and suggests that shared gaze reduces the need for verbal exchange, which can itself become detrimental to performance. One persisting problematic property of the typical small-scale spatial reasoning task is that it is representational and schematic, or more generally, symbolic and grounded in discrete objects (e.g., a map). The separability of visual-motor processing from symbolic, inferential processing leaves open the possibility that established advantages grounded in reflective, symbolic processes will not generalize, or may in fact have alternative explanations.

Researchers generally examine large-scale spatial reasoning as an individual task (Lee & Tversky, 2005), or sequential tasks in which a separate guide pre-formulates instructions for the recipient (Denis,

Michon & Tom, 2007). This methodological choice tightly controls the verbal stimuli, and meets the current capabilities of automated navigational aids, but at the expense of collaborative dialogue that could shed light on both the talker's and recipient's cognitive processes. In actual studies of on-foot navigation, excerpts from think-aloud protocols, deviations, pauses, frequency and duration of instances of consulting the instructions and sketch maps generally support a fundamental role for landmarks in navigation (Daniel & Denis, 2004). Landmarks function at critical decision points, to prompt a change in direction or to prevent a potential divergence from the optimal route. Relative to street signs, landmarks are larger and less arbitrarily named, resulting in better memory despite reduced time reading the directions. Denis interprets this pattern as indicative of the recipient's underlying, mental representation of symbols standing for features in the environment.

Other research questions the language-based symbolic mediation of spatial reasoning (Newcombe & Huttenlocher, 2000; Boroditsky & Prinz, 2008). For example, language provides a fairly coarse representation of continuously-valued space, and entails ambiguity both in the specification and interpretation of relationships depending upon the frame of reference. Such problems clearly do not preclude the use of language to support spatial reasoning, but they do call into question a foundational role for language as a mediator of spatially-oriented action. And so, different or supplemental means of communicating spatial information may be beneficial, particularly in large scale spatial tasks in which shared visual access is not readily available.

We developed a distributed, shared virtual environment with large urban terrains to examine large-scale coordinated navigation. Two-member teams tried to find each other within these urban landscapes. The primary medium of shared access is auditory rather than visual. Under the monaural condition subjects must rely on language to communicate spatial information, but in the 3D audio condition they also have spatialized communications to point to themselves or to another object such as a landmark. In addition, the task involves "movement" through physical space, rather than abstract operation on a schematic. Under some conditions, additional prominent landmarks augment the terrains, enabling examination of the landmark benefit and the possible interaction with the audio condition. That is, the more impoverished monaural audio condition could make subjects more dependent upon landmarks, while the experimental 3D audio condition could render the landmarks unnecessary.

Method

To examine coordinated navigation and team communication, two-person teams, initially separated, navigated in a synthetic large urban environment in order to rendezvous as rapidly as possible. Using a 2X2 design the impact of monaural vs. 3D audio displays was evaluated in terrains with additional prominent visual landmarks and in comparable terrains without such landmarks.

Subjects

A total of eight paid subjects worked in teams of two, with two all male teams, one all female team, and one male-female team. One member of each team played the role of a pararescue jumper (PJ) and the other member played the role of a downed pilot to be rescued (TBR). The subjects ranged in age from 21 to 29 years old. All subjects were from the subject panel maintained by the Battlespace Acoustics Branch at Wright-Patterson Air Force Base and had normal hearing and corrected to normal vision.

Apparatus

The experiment was conducted using two immersive facilities. The Wright State's Virtual Environment, Interactive Technology, And Simulation (VERITAS) facility at Wright-Patterson AFB contains a room-size, 5-projection-surface (4 walls and a floor) virtual environment display system. High-resolution (1200x1200 pixel) stereoscopic images are rendered with Barco Galaxy NW-12 DLP projectors via RealD CrystalEyes shutter glasses. An Intersense IS-900 tracking system monitors the position of the head and handheld Wand. The second was the Appenzeller Visualization Laboratory (AVL) operated by the Wright State Applied Research Corporation in the Joshi Research Center on the campus of Wright State University contains a room-size, 4 projection-surface (3 walls and a floor) virtual environment display system (iSpace, Barco). High-resolution (1400x1050 pixel) stereoscopic images are rendered with Barco Galaxy NH-12 DLP projectors via RealD CrystalEyes shutter glasses. An optical tracking system (ARRTTRACK) monitors the position of the head and handheld wand. VERITAS and AVL are connected via an Internet2 wide area network (WAN) connection. We used the Distributed Interactive Simulation (DIS) (http://usl.sis.pitt.edu/wjj/otbsaf/IEEE1278.1a-1998.pdf) messaging standard to communicate over this network utilizing a DIS software router to send local DIS messages across the WAN to the other location. In both facilities, sounds were spatialized (with individualized head related transfer functions) using the slab3d (v6.5.0; Miller and Wenzel, 2002) and presented via Sennheiser HMD-280-XQ headsets. Close-talking microphone on the headsets allowed subjects in the two facilities to talk to each other. The DIS radio protocol was used to transmit voice communications over the network.

To "move" in VERITAS the subject simply pointed the wand and pushed the joystick on the wand in the desired direction of travel. Because the display system in AVL does not include a rear projection surface it was not viable to move in that direction (i.e., the subject would not be able to "see where they were going"). Therefore, foot pedals were used in AVL that allowed subjects to rotate the virtual environment around them. That is, instead of turning to face the back wall and pointing the wand/joystick in that desired direction of travel as a subject in VERITAS might do, the subject in AVL could turn the environment with the foot pedals so that the imagery that would have been projected on the back wall was projected on the front (or a side) wall. They were then able to point the wand/joystick and move in the desired direction. Subjects learned this system quickly, allowing them to move through the entire virtual environment, and providing a substantially immersive experience. In both environments, a direction indicator appeared in the center of the base of all walls, displaying primary and secondary compass coordinates (N, NW, W, SW, etc.) to let the subjects know what direction they were facing.

In the monaural audio display condition, the DIS radio functioned much like a conventional push-to-talk radio and was actuated by a button on the subject's wand. In the 3D audio display condition, the communications were spatialized so that they were heard as arising from the environment around the listener. Under the control of the talker (based on which of two buttons were pressed on the wand), the talker's voice could be heard as coming from his/her direction or from the direction of an object in the environment that the talker marked using the wand (the audio annotation capability). To do this, the talker pressed the appropriate button on the wand and a red virtual laser extended from the tip of the wand to "infinity." "Shining" the laser on an object caused the talker's voice to be heard as arising form the direction of that object. So that it was clear to the listener which pointing capability was being used, a series of 4 broadband chirps was superimposed on the communication channel immediately after the audio annotation capability was activated.

Procedure

Each trial took place within one of 15 virtual terrains, each measuring 500 m x 500 m. Each terrain was constructed from 4 of the 6 250-m x 250-m "tiles." The tiles could be put together so that any edge in one could be matched up with the edge of another, regardless of orientation. Using different tiles in different orientations, a large number of varying terrains could be created. The tiles were created using Presagis Creator Pro software in the Openflight file. Each of the 6 tiles was used an equal number of times in constructing the 15 terrains. Tile location and orientation of the tiles was not systematically controlled. Each tile contained various possible travel paths, from wide streets to narrow alleyways. Tiles included varying numbers and types of structures, ranging from windowless one-story sheds to large five-story structures with many windows. Under the no additional landmark (NALM) condition, no structures were taller than five stories (Representative scenes from the terrains can be found in the Technical Program section). Under the additional landmark (ALM) condition, additional structures ("landmarks") were added to these same 15 terrains (2 per terrain; spatially separated and on different tiles). Whereas the tiles had industrial and residential areas that were either "generic" or were modeled based on a Moroccan City, the landmarks reflected architecturally and culturally distinct styles (e.g., an Indian sculpture, a modern clock tower, a conventional American water tower, etc.). The landmarks were also designed to be taller than any other structure in the terrains, so that they could be seen from a distance and potentially be used as points of reference by the team members (Figs. 16 and 17 show images of two of the landmarks). The landmarks when present were added to previously vacant locations in the terrains, so no structures were deleted in creating the ALM version of a terrain from the NALM version.

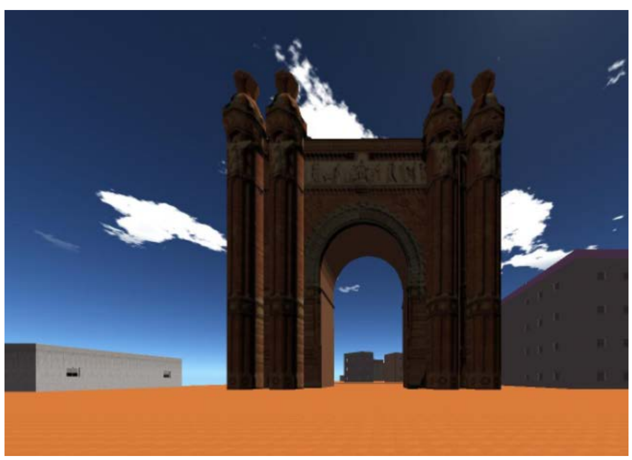


Figure 16. Two screen shot of an archway used as a landmark in the ALM condition.

In each terrain, two pairs of two starting locations were selected by arbitrarily placing one subject near one edge of the terrain (not necessarily within line-of-sight of the edge) and then placing the other subject on the other side of the terrain at roughly the opposite longitude and latitude. The subjects were assigned to the two positions (one for the PJ and one for the TBR); reversing the assignments allowed us to reuse the terrains across experimental conditions.

Task. The subjects were told to imagine themselves in the roles of a downed pilot (TBR) stranded somewhere in a city and a Pararescue jumper (PJ) attempting to rescue the TBR. Subjects understood

that the environment was finite and if they began a simulation near a border of the map, their partner would likely start near the opposite border. The only communication available to the subjects was the radio system controlled by their wands. Subjects were encouraged to let one another know where they were in the environment and what they were doing in order to coordinate a rendezvous as quickly as possible. When the PJ and TBR came within three meters of one another, a message appeared on the front screen indicating that the trial was complete.

Figure 17. Screen shot of a water tower used as a landmark in the ALM condition.

Each terrain contained a total of eight systematically deployed hostiles. Two hostiles appeared near the TBR's starting position and were programmed to move toward that position via a route that would take approximately one minute. Two additional, stationary hostiles blocked the most obvious or direct route between the PJ and TBR so that they could not easily walk directly to one another. In the landmark condition, one stationary hostile was placed at each landmark in order to deter the strategy of simply meeting directly at that position. The remaining stationary hostiles (two in the landmark conditions, four in the no landmark conditions) were placed in locations near likely travel paths for one or both subjects. The hostiles were programmed to shoot the subjects on sight. The hostiles had an effective firing range of exactly 100 meters and when they fired did not miss. Subjects were instructed to "do your absolute best to avoid getting shot." When shot, the subjects would hear a gunshot sound, which was presented with spatialized audio in all conditions, allowing the subject to localize the threat aurally. There would also be a burst of blue pixels emanating from subject's location, similar to a small firework. However, there was no timeout or other objective penalty.

The PJ was armed (with a "virtual gun" actuated by the trigger on the wand), but was instructed not to fire on hostiles unless fired upon or if the PJ could see the TBR and the hostile was blocking the path to the TBR. The PJ had no limit on the range of his or her weapon except for the limitations of screen resolution. The TBR was unarmed.

Terrains also hosted a varied number of civilian entities, but all had at least 20. Civilians appeared throughout the map, approximately half wandering randomly and half stationary, with starting positions tending towards the center of the map. Certain maps had areas likely to host gatherings in real-world settings (a mosque, a school, and a park), and often included a large number of civilian entities

wandering around randomly. In the case of the school, this was true for child entities as well as adult. In a small number of the trials, groups of chicken entities also appeared, starting in one general area but moving randomly throughout the terrain. The PJ was instructed never to shoot civilians.

Design. All pairs experienced all 60 treatment combinations in a 2 (audio conditions) * 2 (landmark conditions) * 15 (trials) repeated measures design. The order of the four combinations of conditions (Monaural/ALM, Monaural/NALM, 3D-audio/ALM, and 3D-audio/NALM) was partially counterbalanced across the four teams as follows. Landmark conditions were run fifteen trials at a time within the audio condition so that both landmark conditions would be experienced before switching to the second audio condition, where the landmark conditions would be repeated.

Trials. One team of two subjects participated at a time. The experimenter read the instructions for the task and audio condition to the subject and answered any questions. Once the subjects received task instructions, they donned the vest that contained the wireless audio receiver/transmitter and put on the headphones with the head tracker attached to the headband and shutter glasses. The subjects sat in chairs and held the wand during the trails

The experiment included four training trials for each of the audio conditions, two that contained landmarks and two that did not. These trials were comparable to actual trials except that the teammates were placed much closer together and generally encountered a higher concentration of hostiles so that they would experience, and later recognize, being shot more easily during the data collection stage. On the first day of either audio condition, teams experienced two training trials consecutively and were given an additional chance to ask questions before data collection began. On subsequent days, only one training trial was conducted before data collection began. The experiment required between 8 and 10 days of participation.

Results and Discussion

Time to rendezvous

The performance measure of major interest was the time required to complete the rendezvous task. We replaced completion time outliers that were more than 3 SDs from the mean for that team and condition with the mean for that team and condition. We examined performance with an ANOVA, including Team (1, 2, 3, 4), Audio Display (monaural, 3D audio), Landmark (NALM, ALM), and Landmark * Audio Display, and with Trial as a continuously valued variable. Due to the low number of teams, and the resulting small df error terms in the classic repeated measures decomposition, we used an aggregated subject*treatment error term for all tests. Single df manipulations obviate concern for sphericity. The analysis demonstrates reduced completion times under the 3D audio condition ($F(1,232) = 20.77$, $p < .0001$, M(3D audio) = 162.36, M(monaural) = 200.78 , with some concern for homogeneity of variance due to the df in the error term ($Fmax(1,119) = 1.51$, $p < .05$). Results for individual teams are shown in Figure 18. Neither the landmark manipulation nor the interaction of landmark and audio display were significant ($F(1,232) = .12$, $p < .72$, and $F(1,232) = .69$, $p < .41$). F(max) tests suggest concern for homogeneity of variance in the landmark main effect ($Fmax (1,116) = 2.34$, $p < .05$) and particularly the interaction ($Fmax (3,59) = 6.01$, $p <.05$). The reduction in error variance relates to the more consistent response times of 3D audio and the ALM conditions. This finding made it reasonable to examine simple effects by landmark condition, using pooled error terms unique to the means in question. However, both ALM and NALM conditions suggest an advantages for 3D audio, $t(59) = 5.19$, $p<.05$ and $t(59) = 2.16$, $p < .05$, respectively.

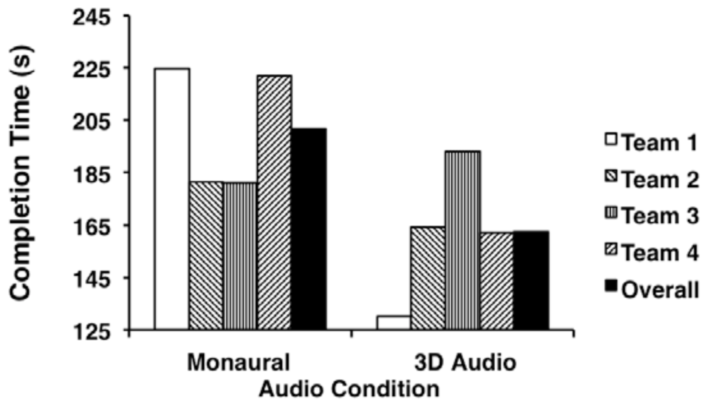


Figure 18. Average time to complete the rendezvous task each team under the two audio conditions. The black bars show performance averaged across teams.

These results indicate that spatializing a communication channel can provide usable information about a teammate's location in a team navigation task. Although this task was explicitly spatial and implied a specific use for the information provided by the 3D audio display (i.e., walk toward your teammate's voice), we expect spatializing communication channels to promote shared situation awareness and team coordination in a variety of combat situations. That is, "knowing where your buddies are" is likely to be generally useful. On the other hand, casual observations indicate that the subjects rarely used the audio annotation capability, and when it was used the subjects did not appear to be marking landmarks to help orient each other and coordinate their rendezvous. More thorough analyses of the current data should help clarify the subjects' use (and lack of use) of audio annotation. Perhaps clearer instructions or a terrain design in which prominent landmarks were visible at a greater distance would have encouraged the use of this capability. It is also possible that the availability to two spatial capabilities (marking the talker location and marking another location) may have been confusing or awkward and so the subjects relied on just one of them. Separating these two 3D audio capabilities in future studies may help clarify this result.

The lack of a landmark effect may simply reflect the fact that the small number of additional landmarks in these large terrains may have been insufficient to influence overall performance. However, the absence of a landmark effect in the outcome measure merits investigation for two reasons. First, the absence of an effect is operationally counterintuitive. Highly confusable terrain is a known challenge in military navigation (DuBois, Shalin, Levi & Borman 1997/1998) and the presence of additional prominent landmarks was expected to reduce this problem. Second, the finding is inconsistent with the scholarly literature (e.g., Daniel & Denis, 2004).

The experiment software recorded the communications between the PJ and the TBR as they performed the team navigation task. These recordings will allow for a more fine-grained (linguistic) analysis that may reveal a landmark effect, or may reveal compensatory strategies that obviate the role of landmarks in this task. We plan to complete such linguistic analyses, but these analyses are beyond the scope of the current paper.

Use of communication channels

We also expect that subjects' communications would be different in the 3D audio conditions, because there would be less need for complex discussion of spatial relations. Again, we plan to conduct linguistic

analyses in the future to examine these communications in detail. However, some preliminary insight into the nature of these communications can be gleaned by considering how much the subjects utilized the communication options available to them.

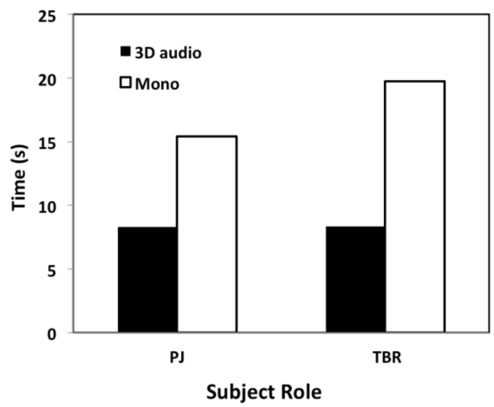


Figure 19. Average duration of push-to-talk button presses under 3D audio and Monaural conditions for subjects in the PJ and TBR roles.

Figure 19 compares the use of the push-to-talk communication channel under the monaural condition to the use of the push-to-talk communication channel that spatialized the talker's voice to his/her location under the 3D audio condition. As can be seen, the average duration of communications (i.e., button presses) under the 3D audio condition was shorter, compatible with a reduced need to transmit spatial information. The linguistic analyses may reveal that subjects used fewer words with 3D audio or suspended concern for simulating the recipient's perspective, as compared to the monaural condition in which they may have paused longer, used more words, and demonstrated more misunderstanding of their teammate or their situation.

Overall, these preliminary results provide further evidence for the potential utility of 3D audio in the battlespace and extend the findings of Gilkey et al. (2007), Ephrem et al. (2008), and those reported in Task 4 from situations involving teams composed of an airborne operator and a ground soldier to teams composed of two ground soldiers. The planned linguistic analyses should help to clarify how subjects are using this technology and why we did not find an impact of our landmark manipulation.

References

Brennan, S.E. & Clark, H.H. (1996). Conceptual pacts and lexical choice in conversation. Learning, *Memory and Cognition, 2,* 1482-1493.

Brennan, S.E., Chen, X., Dickenson, A., Neider, M.B., & Zelinsky, G.J. (2008). Coordinating cognition: The costs and benefits of shared gaze during collaborative search. *Cognition, 106*, 1465-1477.

Clark, A. (1999). Visual awareness and visuomotor action. *Journal of Consciousness Studies, 6:11-12*, 1-18.

Clark, H.H. & Wilkes-Gibbs, D. (1986). Referring as a collaborative process. *Cognition, 22,* 1-39.

Daniel, M., Denis, M. (2003). The production of route directions: Investigating conditions that favour conciseness in spatial discourse. *Applied Cognitive Psychology, 18*(1), 57-75.

Denis, M., Michon, P. E., & Tom, A. (2007). Assisting pedestrian wayfinding in urban settings: Why references to landmarks are crucial in direction giving. In G. L. Allen (Ed.), *Applied spatial cognition: From research to cognitive technology* (pp. 25-52). Mahway, NJ: Lawrence Erlbaum.

DuBois, D. & Shalin, V.L., Levi, K.R. & Borman, W.C. (1997/1998). A cognitively-oriented approach to task analysis and test development. *Training Research Journal, 3,* 103-142.

Ephrem, A. J., Finomore, V. S., Gilkey, R. H., Newton, R. M., Romigh, G. D., Simpson, B. D., Brungart, D. S., & Cowgill, J. L. (2008). An "Audio Annotation" technique for intuitive communication in spatial tasks. In Proceedings of the Human Factors and Ergonomics Society 52nd Annual Meeting, 52, 2127-2131.

Gilkey, R. H., Simpson, B. D., Brungart, D. L., Cowgill, J. L., and Ephrem, A. J. (2007). 3D Audio Display For Pararescue Jumpers. Proceedings of the HFES 51st Annual Meeting, 51, 1349-1352.

Green, C. & Hummel, J.E. (2004). Relational perception and cognition: Implications for cognitive architecture and the perceptual cognitive interface. *The Psychology of Learning and Motivation, 4,* 201-231. Elsevier.

Hanna, J.E., Tanenhaus, M.K. & Trueswell, J.C. (2003). The effects of common ground and perspective on domains of referential interpretation. *Journal of Memory and Language, 49,* 43-61.

Lee, P.U. & Tversky, B. (2005). Interplay between visual and spatial: The effect of landmark descriptions on comprehension of route/survey spatial descriptions. *Spatial Cognition and Computation, 5(2&3),* 163-185.

Miller, J.D. and Wenzel, E.M. (2002) Recent Developments in SLAB: A Software-Based System for Interactive Spatial Sound Synthesis. *Proceedings of the International Conference on Auditory Display*, ICAD 2002, Kyoto, Japan, pp. 403-408.

Monk, A.F. & Gale, C. (2002). A look is worth a thousand words: Full gaze awareness in video-mediated conversation. *Discourse Processes, 33(3),* 257-278.

Newcombe, N. S., & Huttenlochner, J. (2000). *Making space: The development of spatial representations and reasoning.* Cambridge, MA: MIT Press.

Richardson, D.C. & Dale, R. (2005). Looking to understand: The coupling between speakers' and listeners' eye movements and its relationship to discourse comprehension. *Cognitive Science, 29,* 1045-1060.

Tversky, B., Kim, J. & Cohen, A. (1999). Mental models of spatial relations and transformations from language. In: G. Rickheit & C. Habel (Eds.) *Mental Models in Discourse Processing and Reasoning,* pp. 239-258. Elsevier Science.

Velichokovsky, B.M. (1995). Communicating attention: Gaze position transfer in cooperative problem solving. *Pragmatics & Cognition, 3(2),* 199-224.

6.0 SECTION 6: RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Introduction

A great deal was accomplished in the program funded by agreement FA8650-10-2-6048. As can be seen form the results, everything did not work out as anticipated regarding the performance of spatialized audio. However, the tasks that were completed demonstrated the flexibility and value in using virtual environments to create compelling environment in which to evaluate technology, even using inexperienced subjects with a limited amount of training.

6.2 Results

1. Completed 3 of 4 Tasks defined in the initial Statement of Work

   The project was influenced by results from experiments that were completed immediately prior to the kick-off for the program. As noted in the report, these raised concerns about the integrity of the auditory environment being tested and the scope of work was changed making it impossible to complete Task 2 which addressing the issue of ambient noise.

2. Task 1
   a. As noted, the team had to backtrack to deal with previously inconsistent psychophysical results.
   b. Task 1.1 was added to the program to put in place a comprehensive validation and verification procedure for the audio environment and to develop and load accurate HRTF's for all new subjects.
   c. Despite Task 1.1, the psychophysical results still show unacceptable performance in the IVP environment for front/back and elevation for all subjects.

3. Task 4
   a. This was a very thorough evaluation of the spatialized audio system with carefully controlled deployment of threats to collect 1620 performance measurements in a simulated urban environment.
   b. The results consistent with Task 1 problems in terms of performance correlated to front/back and elevation discrimination
   c. The results showed that performance using spatialized audio was improved over simple mono and semantic/descriptive audio.

4. Task 3
   a. The implementation of an all DIS environment allowed for the capture of dialog between participants and although there was not adequate time or resources to analyze these they provide a rich database for future projects.

   b. While available, subjects made limited use of the audio annotation features of the system, possibly because it requires more training or that it is less useful that simply having the participants maintain a continuing dialogue and so "home in" on each other.

5. Despite the results from Task 1, the overall results showed that 3D audio improved performance in both Task 3 and 4.

6. Technical results were included in Section 4.4 but the key ones were:
   a. There was significant enhancement of IVP capabilities
      i. Tiled terrain
      ii. Controller
      iii. Scenario Generator that could provide real time understanding of the field of view for a subject that is almost impossible to determine in other settings.
      iv. ALF simulation showed flexibility of the IVP.
   b. DIS conversion very time consuming - limited value given the results of Tasks 1 and 4
   c. Data complexity managed using dual architecture - just adequate
   d. Have architecture to guide future development

6.3 Conclusions (lessons Learned)

1. Developing effective baselines against which to compare spatialized audio was difficult and time consuming. This was most significant in Task 4 for which 540 semantic cues had to be developed, recorded and tested.
2.
   3. Task 1
      a. Getting effective psychophysical results from 3D audio displays is still a challenge in all but the most controlled environments, i.e. the ALF. Developing methods that will deliver accurate results is important if such a system is to be deployed in the field.
      b. This Task showed that having the correct HRTF's loaded is important to obtain accurate localization of sounds. The fact that these rae not developed in the environment in which they are applied may contribute to the results observed in Task ,1 which reinforces the need for more research on the ambient noise issue.
      c. Development of ALF analog showed flexibility of IVP to create different experimental environments.
   4. Task 4
      a. A Scenario Generator capability could a critical differentiator for using VR because it is possible to establish accurate "ground truth" about what an individual or group of individuals can see.
      b. Future experiments should be done in less controlled environments than the "convoy" model that was applied in this Task.

   5. Task 3

   a. The design did not show the potential for audio display to offload tasks form a subject. The next round should build on the present work to focus more effectively on this. For example, knowing where a team member is as a secondary task in working to a more complex primary obejctove , like seizing a building.
   b. Future efforts should build on this Task, not Tasks 1 and 4

6. Technical

   a. Technical development and support requirements were significantly under estimated.
   b. The larger, tile based terrains worked very effectively
   c. Management and analysis of data from trial in the IVP, including recording dialogues between subjects is now the most significant challenge going forward.
   d. Using DIS may be a limit in terms of experimental complexity.
   e. The skills needed to develop and support the use of sophisticated visualization environment, like the IVP is very limited and takes time to develop.

6.4 Recommendations

1. Bring in PJ's a Subject Matter Experts to work in the environment using the spatial audio display. The results warrant the investment of their time and would provide essential baselines, feedback and guidance for future experiments.

2. Build on Task 3 for next round of experiments, i.e. stop revisiting Task 1 and 4 unless for ambient noise experiments
   a. Develop primary tasks that require coordination etc and use 3D audio to manage task loading
   b. Create experiments that force the use of annotation to understand how to apply. For example, creating input from a source outside the environment like a UAV operator or Command and Control Center, which must involve using annotation.

3. Develop experiments to examine how 3D audio works in the CSAR mission context. Specifically, does it operate through perception/action versus cognition?

4. Expand the size of teams complementing real subjects with avatars, i.e. digital participants with simpler behaviors to increase the complexity of trials.

5. Develop experiments to extend use of spatialized audio to Command and Control environments, intelligence analysis, and UAV management. This could be a powerful adjunct to primarily visual displays and monaural voice communications.

6. Technical development
   a. Complete the GUI based IEC
   b. Develop an architecture for data management and implement
   c. Extend terrain tiles to include elevation and building interiors with managed hierarchies of objects

d. Evaluate alternatives to DIS for complex gaming and training
e. Establish a program at WSU to train developers for advanced visualization environments, like the IVP.

7.0 SECTION 7 APPENDICES

1. IDD Messaging Specifications
2. IEC Specifications
3. Scenario Builder Extract Sample
4. XML Parameter File Sample
5. Terrain Samples

NOTE; Copies of software are available from a secure source repository.

APPENDIX 1

IVP IDD
Ver. 10
Jeffrey Cowgill
Jim Hooker
John Stewart

Introduction

This document is the Interface Description Document (IDD) for the Integrated Visual Platform (IVP). The communication between the components of the IVP will be based upon the DIS protocol (IEEE 1278 series of standards). This document describes the format and contents of DIS PDUs used in the IVP to communicate between various applications.

Messages

The IVP will use the DIS CommentR PDU to send all messages. The commentR PDU has a variable number of fixed and variable length fields, which are allocated differently for each message type with the exception of the Fixed Length Slot 1. Fixed Length Slot 1 always holds a 32-bit integer message type for the rest of the CommentR PDU.

The following enumerated values are used in the IVP Messages:

Table 2: Message IDs

Value	Message Type
0	None
1	IVE Change Time Message
2	IVE Change Terrain Message
3	IVE Change Weather Message
4	IVE ACF State Request Message
5	IVE Display Text Message
6	IVE Change Position Message
7	IVE Show Sphere Message
8	IVE Hide Sphere Message
9	IVE Boresight Message
10	IVE Indicate Speaker Message
11	IVE Stop Indicate Speaker Message
12	IVE State Message
13	Visual Ready Message
14	Speaker Indicated Message
15	Wand Tracker Message
16	Head tracker Message
17	Hand Tracker Message
18	Experiment Settings Message
19	IVE Start Message
20	IVE Pause/Freeze Message
21	IVE Stop Message
22	IVE Exit Message
23	IAE Load HRTF
24	IAE Load Configuration
25	IAE Create Wave Source Message
26	IAE Destroy Sound Source Message
27	IAE HRTF Status
28	IAE Wave Played Message
29	Trial Start Message

30	Trial End Message
31	IVE Follow Path Message
32	IVE Sniper Trial End
33	ITE Load Scenario
34	ITE Reset Scenario
35	IAE Stop All Sounds
36	IDB Create New Database
37	IDB Save Database
38	IDB Request Score
39	IEC Participant Score
40	IVE Set Motion Model
41	Application Kill
42	Application Running

For the Sender ID information we will use an Exercise ID = 1, Site ID = 1 for VERITAS, 2 for AVL. So the ID will be 1:(1 or 2):(Application # below)

Table 3: Application IDs

Value	Application
0	None
1	IEC
2	iSpace IVE
3	iSpace IAE
4	CAVE IVE
5	CAVE IAE
6	ITE (VR Forces)
7	Operator Station
8	CADWALL
9	Data Logger

Table 3: Weather Types

Value	Weather
0	Clear
1	Scattered
2	Overcast

Table 4: Motion Model Types

Value	Motion Model
1	Rudder Pedals
2	Tank
3	Point and Go

IEC Messages

Application Launch

Application Launch messages are an internal message for the IEC. The application launch message contains the following data fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Application Start value
Application ID	Fixed	2	Long	See Enum	Application ID Enumeration
Soft Launch	Fixed	3	Long	BOOL	Flag for soft launch on execute

Application Start

Application Start messages are issued by the IEC and are received by the other applications in the IVP. All applications will have to monitor all Application Start messages and respond to their Application ID. The application start message contains the following data fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Application Start value
Application ID	Fixed	2	Long	See Enum	Application ID Enumeration

Application Pause

Application Pause messages are issued by the IEC and are received by the other applications in the IVP. All applications will have to monitor all Application Pause messages and respond to their Application ID. The Application Pause message contains the following data field:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Application Pause value
Application ID	Fixed	2	Long	See Enum	Application ID Enumeration

Application Stop

Application Stop messages are issued by the IEC and are received by the other applications in the IVP. All applications will have to monitor all Application Stop messages and respond to their Application ID. The Application Stop message contains the following data field:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Application Stop value
Application	Fixed	2	Long	See	Application ID Enumeration

ID				Enum	

Application Terminate

Application terminate messages are issued by the IEC and are received by the other applications in the IVP. All application will have to monitor all Application Terminate messages and respond to their Application ID. The Application Terminate message contains the following data field:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Application Terminate value
Component Location	Fixed	2	Long	See Enum	Component Location Enumeration

Application Kill Message

The Application Kill message is an internal message for the IEC. The IEC uses the message when it wants to force the termination of an application. The Application Kill message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Application Kill Message value.
Application ID	Fixed	2	Long	See Enum	See application enumeration.

Experiment Settings Message

The Experiment Settings messages are issued by the IEC to the IVEs. The IEC sends the message at the start of an experiment so the IVE can set up the proper data collection files. The Experiment Settings message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Hand Tracker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Subject IDs	Var	1	Char	ASCII	64 character list of subject ids, coma delimited
Team Number	Fixed	3	Long	>= 0	Team Number of subjects to run
Block Number	Fixed	4	Long	>= 0	Block Number for the run
Condition Number	Fixed	5	Long	>=0	Condition Number for the run
Experiment ID	Var	2	Char	ASCII	64 character Experiment ID for the run
Subject Ages	Var	3	Char	ASCII	64 character coma delimited list
Subject Sexes	Var	4	Char	ASCII	64 character coma deilimted list 0=male, 1=female

IVE Change Terrain

The IVE Change Time messages are issued by the IEC and received by the IVE applications only. The IVE Change Terrain message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Change Terrain Message value
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Terrain File Name	Var	1	String	ASCII	64 character file name without extension

IVE Change Weather

The IVE Change Weather messages are issued by the IEC and received by the IVE applications only. The IVE Change Terrain message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Change Weather value
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Weather	Fixed	3	Long	See Enum	Weather Type Enumeration

IVE State Request

The IVE ACF State Request messages are issued by the IEC and received by the IVE applications only. The IVE Get ACF State message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE ACF State Request Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration

IVE Display Text

The IVE Display Text messages are issued by the IEC and received by the IVE applications only. The IVE Display Text message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Display Text Message value
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Display Text	Var	1	String	ASCII	128 character text to display

IVE Change Position

The IVE Display Text messages are issued by the IEC and received by the IVE applications only. The IVE Display Text message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Change Position Message value
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
X Position	Fixed	3	Double	Any	X Position of observer
Y Position	Fixed	4	Double	Any	Y Position of observer
Z Position	Fixed	5	Double	Any	Z Position of Observer
Heading	Fixed	6	Double	Any	Heading of observer
Pitch	Fixed	7	Double	Any	Pitch of observer
Roll	Fixed	8	Double	Any	Roll of observer

IVE Change Time

The IVE Change Time messages are issued by the IEC and received by the IVE applications only. The IVE Change Time contains the following data fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Change Time Message value
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Time Of Day	Fixed	3	Double	[0,24)	Time of day in decimal hours

IVE Show Sphere

The IVE Show Sphere messages are issued by the IEC and received by the IVE applications only. The IVE Show Sphere message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Show Sphere Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration

IVE Hide Sphere

The IVE Hide Sphere messages are issued by the IEC and received by the IVE applications only. The IVE Hide Sphere message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Hide Sphere Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration

IVE Boresight

The IVE Boresight messages are issued by the IEC and received by the IVE applications only. The IVE Boresight message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Boresight Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Boresight Flag	Fixed	3	Long	Bool	False = turn off, True = turn on

IVE Speaker On

The IVE Indicate Speaker messages are issued by the IEC and received by the IVE applications only. The IVE Indicate Speaker message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Indicate Speaker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Speaker Number	Fixed	3	Long	0-275	Speaker number to indicate with LEDs
LED value	Fixed	4	Long	0-4	The number of LEDs to turn on

IVE Speaker Off

The IVE Indicate Speaker messages are issued by the IEC and received by the IVE applications only. The IVE Indicate Speaker message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Stop Indicate Speaker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Speaker Number	Fixed	3	Long	0-275	Speaker number to stop indicating with LEDs

Trial Start Message

The Trial Start message is issued by the IEC to the IVEs. The IEC sends the message at the start of a trial/event so the IVE can setup and record the proper data. The Trial Start message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Hand Tracker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Trial/Event Number	Fixed	3	Long	>= 1	The trial or event number being started
Trial/Event	Fixed	4	Long	>= 0	An index associated with different types of

Type					events or trials when multiple types are used in the same experimental block

Trial Stop Message

The Trial Start message is issued by the IEC to the IVEs. The IEC sends the message at the start of a trial/event so the IVE can setup and record the proper data. The Trial Start message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Hand Tracker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Trial/Event Number	Fixed	3	Long	>= 1	The trial or event number being stopped, if this number does not match an already started trial, then it is ignored.
Response/trial time	Fixed	4	Double	>= 0	The time the trial took to complete, calculated by the IEC

Follow Path Message

The Follow Path message is issued by the IEC to the IVEs. The IEC sends the message to start the IVE following a defined path or to disable a currently followed path. The Follow Path message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Hand Tracker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Path On/Off	Fixed	3	Bool	0 or 1	If false any paths currently being followed will be stopped and the IVE will return to the walk motion model, if true the IVE will load the path information provided and start the motion model
Path Filename	Var	1	Char	ASCII	The file name of the path file containing the waypoints, the "acf" directory is the assumed location, 256 byte length
Navigation Filename	Var	2	Char	ASCII	The file name of the navigation file, the "acf" directory is the assumed location, 256 byte length

IVE Set Motion Model Message

The IVE Set Motion Model message is issued by the IEC to the IVE. The IEC sends the message when it wants the IVE to change the current motion model. The IVE will set the motion model according to the parameters of the message. The IVE Set Motion Model message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See	Message Type enumeration - IVE Set Motion

				Enum	Model Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Motion Model	Fixed	3	Long	See Enum	Motion model to activate.
Ground Clamp	Fixed	4	Long	Flag	Flag to enable or disable ground clamp. 0 = disable, 1 = enable
Intersection Test	Fixed	5	Long	Flag	Flag to enable or disable intersection testing. 0 = disable, 1 = enable.

IAE Load HRTF Message

The IAE Load HRTF messages are issued by the IEC. The IAE Load HRTF message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IAE Load HRTF value
IAE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
HRTF File	Var	1	String	ACSII	64 char file name of the HRTF file to load without path or extension

IAE Load Configuration Message

The IAE Load Configuration messages are issued by the IEC. The IAE Load Configuration message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IAE Load HRTF value
IAE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Configuration File	Var	1	String	ACSII	64 char file name of the Configuration file to load without path or extension

IAE Create Wave Source Message

The IAE Create Wave Source messages are issued by the IEC. The IEC sends the message whenever a wave sound source needs to be configured by the IAE during runtime. When received the IAE will set any sources matching this type to equal this wave file, or create a new one if no sources match. The IAE Create Wave Source message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IAE Create Entity value
IAE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Kind	Fixed	3	Long	Any	DIS EntityKind
Domain	Fixed	4	Long	Any	DIS Domain
Country	Fixed	5	Long	Any	DIS Country

Category	Fixed	6	Long	Any	DIS Category
Subcategory	Fixed	7	Long	Any	DIS Sub-category
Specific	Fixed	8	Long	Any	DIS Specific
Other	Fixed	9	Long	Any	DIS Extra
Gain	Fixed	10	Long	>=0	Gain in hundredths of dB stored as an int32
MinDistance	Fixed	11	Long	>=0	Minimum distance in hundredths of meters
MaxDistance	Fixed	12	Long	>=0	Maximum distance in hundredths of meters
Mono	Fixed	13	Long	Bool	Mono = 1, Spatial = 0
Loop	Fixed	14	Long	Bool	Looping = 1, Not Looping = 0
File	Var	1	String	UTF8	256 byte Filename, including path, to the wave file

IAE Destroy Sound Source Message

The IAE Destroy Entity messages are issued by the IEC. The IEC sends the message whenever a sound source needs to be destroyed by the. The IAE Destroy Entity message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IAE Destroy Entity value
IAE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Kind	Fixed	3	Long	Any	DIS EntityKind
Domain	Fixed	4	Long	Any	DIS Domain
Country	Fixed	5	Long	Any	DIS Country
Category	Fixed	6	Long	Any	DIS Category
Subcategory	Fixed	7	Long	Any	DIS Sub-category
Specific	Fixed	8	Long	Any	DIS Specific
Other	Fixed	9	Long	Any	DIS Extra

IAE Stop All Sounds Message

The IAE Stop All Sounds message is issued by the IEC to the IAE. The IEC sends the message when it wants the IAE to stop generating all sounds. The IAE Stop All Sounds message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IAE Stop All Sounds Message value.
IAE Location	Fixed	2	Long	See Enum	IAE Location Enumeration

ITE Load Scenario Message

The ITE Load Scenario message is issued by the IEC to the ITE. The IEC sends the message when it wants the ITE to load a new scenario. The ITE Load Scenario message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - ITE Load Scenario Message value.

ITE Location	Fixed	2	Long	See Enum	VR Forces Location Enumeration
Path Filename	Var	1	Char	ASCII	The file name of the file containing the scenario, 256 byte length max

ITE Reset Scenario Message

The ITE Reset Scenario message is issued by the IEC to the ITE. The IEC sends the message when it wants the ITE to reset the currently loaded scenario to the beginning. The ITE Reset Scenario message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - ITE Reset Scenario Message value.
ITE Location	Fixed	2	Long	See Enum	VR Forces Location Enumeration

IDB Create New Database Message

The IDB Create New Database message is issued by the IEC to the IDB. The IEC sends the message when it wants the IDB to create a new database with the specified filename. The IDB Create New Database message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IDB Create New Database Message value.
ITE Location	Fixed	2	Long	See Enum	VR Forces Location Enumeration
Path Filename	Var	1	Char	ASCII	The file name of the new database file, 256 byte length max

IDB Save Database Message

The IDB Save Database message is issued by the IEC to the IDB. The IEC sends the message when it wants the IDB to stop recording and save off the database file. The IDB Save Database message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IDB Save Database Message value.
IDB Location	Fixed	2	Long	See Enum	IDB Location Enumeration

IDB Request Score Message

The IDB Request Score message is issued by the IEC to the IDB. The IEC sends the message when it wants the IDB to calculate the participant score for a demo run. The IDB Request Score message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See	Message Type enumeration - IDB Request

				Enum	Score Message value.
IDB Location	Fixed	2	Long	See Enum	IDB Location Enumeration

General Application Messages

Application Running Message

The Application Running message is sent by applications to the IEC when they have fully initialized and are ready to run. The IEC uses this message to know when the system is up and running. The Application Running message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Application Running Message value.
IEC ID	Fixed	2	Long	See Enum	See IEC ID in the application enumeration.
Application ID	Fixed	2	Long	See Enum	See application enumeration. Application ID that is issuing message.

IVE Messages

Visual Ready Message

The Visual Ready messages are issued by the IVE and received by the IEC application only. The IVE sends the message when it is ready to run after receiving a Application Start message. The ACF State message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration Visual Ready Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration

Speaker Indicated Message

The Speaker Indicated messages are issued by the IVE and received by the IEC application only. The IVE sends the message when the participant indicates a speaker after receiving an Indicate Speaker message. The Speaker Indicated message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Speaker Indicated Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Speaker Number	Fixed	3	Long	0-275	Speaker number that participant indicated

ACF State Message

The ACF State messages are issued by the IVE and received by the IEC application only. The ACF State message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - ACF State Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Main ACF File	Var	1	String	ACSII	64 char file name of the main ACF file in use without path or extension
Local ACF File	Var	2	String	ASCII	64 char file name of the local ACF file in use without path or extension

Wand Tracker Message

The Wand Tracker messages are issued by the IVE. The IVE sends the message at a predetermined rate. The Wand Tracker message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Wand Tracker Message value
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Trigger	Fixed	3	Long	Bool	Trigger status
View Rotate Left Status	Fixed	4	Long	Bool	View Rotate Left Button Status
View Rotate Right Status	Fixed	5	Long	Bool	View Rotate Right Status
Audio	Fixed	6	Long	Bool	Audio On Button Status
Joystick X	Fixed	7	Double	Any	Joystick X value
Joystick Y	Fixed	8	Double	Any	Joystick Y value
X Position	Fixed	9	Double	Any	Wand X Position value
Y Position	Fixed	10	Double	Any	Wand Y Position value
Z Position	Fixed	11	Double	Any	Wand Z Position value
Heading	Fixed	12	Double	Any	Wand Heading value
Pitch	Fixed	13	Double	Any	Wand Pitch value
Roll	Fixed	14	Double	Any	Wand Roll value

Head Tracker Message

The Head Tracker messages are issued by the IVE. The IVE sends the message at a predetermined rate. The Head Tracker message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Head Tracker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration

X Position	Fixed	3	Double	Any	Head X Position value
Y Position	Fixed	4	Double	Any	Head Y Position value
Z Position	Fixed	5	Double	Any	Head Z Position value
Heading	Fixed	6	Double	Any	Head Heading value
Pitch	Fixed	7	Double	Any	Head Pitch value
Roll	Fixed	8	Double	Any	Head Roll value

Hand Tracker Message

The Head Tracker messages are issued by the IVE. The IVE sends the message at a predetermined rate. The Head Tracker message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Hand Tracker Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
X Position	Fixed	3	Double	Any	Hand X Position value
Y Position	Fixed	4	Double	Any	Hand Y Position value
Z Position	Fixed	5	Double	Any	Hand Z Position value
Heading	Fixed	6	Double	Any	Hand Heading value
Pitch	Fixed	7	Double	Any	Hand Pitch value
Roll	Fixed	8	Double	Any	Hand Roll value

IVE Sniper Trial End Message

The IVE Sniper Trial End message is issued by the IVE to the IEC. The IVE sends the message when it detects that the participant has hit the Sniper location. The IVE Sniper Trial End message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IVE Sniper Trial End Message value.
IVE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Trial/Event Number	Fixed	3	Long	>= 1	The sniper trial number being ended.

IAE Messages

IAE HRTF Status Message

The IAE HRTF Status Message is sent out anytime the IAE loads an HRTF file:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Hand Tracker Message value.
IAE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Status	Fixed	3	Long	Bool	Success = 1, Failure = 0
HRTF	Var	1	Char	ASCII	256 byte HRTF filename and path of HRTF

					on success. Empty string on failure.

IAE Wave Played Message

The IAE Wave Played Message is sent out by the IAE when a wave sound entity is first created to record the wave file used for that entity:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - Hand Tracker Message value.
IAE Location	Fixed	2	Long	See Enum	Immersive Space Location Enumeration
Status	Fixed	3	Long	Bool	Success = 1, Failure = 0
Kind	Fixed	4	Long	Any	DIS EntityKind of sound source
Domain	Fixed	5	Long	Any	DIS Domain
Country	Fixed	6	Long	Any	DIS Country
Category	Fixed	7	Long	Any	DIS Category
Subcategory	Fixed	8	Long	Any	DIS Sub-category
Specific	Fixed	9	Long	Any	DIS Specific
Other	Fixed	10	Long	Any	DIS Extra
Gain	Fixed	11	Long	>=0	Gain in hundredths of dB stored as an int32
MinDistance	Fixed	12	Long	>=0	Minimum distance in hundredths of meters
MaxDistance	Fixed	13	Long	>=0	Maximum distance in hundredths of meters
Mono	Fixed	14	Long	Bool	Mono = 1, Spatial = 0
Loop	Fixed	15	Long	Bool	Looping = 1, Not Looping = 0
Wave File	Var	1	Char	ASCII	256 byte Wave filename, including path.

IDB Messages

IEC Participant Score Message

The IEC Participant message is issued by the IDB to the IEC. The IDB sends the message in response to an IDB Request Score message. The IEC Participant Score message contains the following fields:

ID	F/V	Slot	Type	Range	Description
Message Type	Fixed	1	Long	See Enum	Message Type enumeration - IEC Participant Score Message value.
IECLocation	Fixed	2	Long	See Enum	IEC Location Enumeration
Score	Fixed	3	Long	Pos	Participant Score for demo run

APPENDIX 2

daytaOhio

SOFTWARE REQUIREMENTS SPECIFICATION

IVP Experiment Controller

Author: James J. Hooker
Version: 1.1.0
Date: 02/12/2010

Document Revision History

Version	Date	Description	Revision Author
1.0.0	**02/12/2010**	**Created**	**JJH**
1.1.0	**2/22/2010**	**Updated after review with comments from JC and MM**	**JJH**

Table of Contents

1 INTRODUCTION......91

1.1 OVERVIEW......91
1.2 PURPOSE......91
1.3 SCOPE......91
1.4 STRUCTURE AND ORGANIZATION OF THIS DOCUMENT......91

2 OVERALL DESCRIPTION......91

3 SPECIFIC REQUIREMENTS......95

3.1 FUNCTIONALITY......95
3.1.1 The IEC shall allow the user to create an experiment sequence......95
3.1.1.1 The IEC shall allow the user to add, edit and delete instruction steps from an experiment sequence 96
3.1.1.2 ...... The IEC shall allow the user to add, edit and delete commands from an experiment 96
3.1.1.3 ...... The IEC shall allow the user to add edit and delete scenarios from an experiment 96
3.1.2 The IEC shall interface with the AVL......96
3.1.2.1 ...... The IEC shall interface with the AVL iSpace IVE 96
3.1.2.1.1 The IEC shall configure the iSpace IVE......96
3.1.2.1.1.1 The IEC shall set the IVE initial state......96
3.1.2.1.1.2 The IEC shall set the IVE start location......96
3.1.2.1.1.3 The ICE shall set the IVE main ACF file......96
3.1.2.1.1.4 The IEC shall set the IVE location ACF file......96
3.1.2.1.2 The IEC shall command the iSpace IVE......97
3.1.2.1.2.1 The IEC shall set the IVE observer position......97
3.1.2.1.2.2 The IEC shall request the current IVE configuration ACF file name......97
3.1.2.1.2.3 The IEC shall command the IVE to load a terrain database......97
3.1.2.1.2.4 The IEC shall command the IVE to set the time of day of the environment......97
3.1.2.1.2.5 The IEC shall command the IVE to set the weather in the environment......97
3.1.2.1.2.6 The IEC shall command the IVE to display text......97
3.1.2.1.2.7 The IEC shall command the IVE to exit......97
3.1.2.1.2.8 The IEC shall command the IVE to start a trial......97
3.1.2.1.2.9 The IEC shall command the IVE to stop a trial......97
3.1.2.1.3 The IEC shall monitor the status of the AVL iSpace IVE......97
3.1.2.2 ...... The IEC shall interface with the iSpace IAE 98
3.1.2.2.1 The IEC shall configure the iSpace IAE......98
3.1.2.2.2 The IEC shall command the iSpace IAE......98
3.1.2.2.3 The IEC shall monitor the status of the iSpace IAE......98
3.1.2.3 ...... The IEC shall interface with the AVL VR-Forces AI 98
3.1.2.3.1 The IEC shall configure the AVL VR-Forces AI......98
3.1.2.3.2 The IEC shall command the AVL VR-Forces AI......98
3.1.2.3.3 The IEC shall monitor the status of the AVL VR-Forces AI......98
3.1.2.4 ...... The IEC shall interface with the AVL Stealth Viewer 98
3.1.2.4.1 The IEC shall configure the AVL Stealth Viewer......98
3.1.2.4.2 The IEC shall command the AVL Stealth Viewer......98
3.1.2.5 ...... The IEC shall interface with the AVL Data Collection Application 98
3.1.2.5.1 The IEC shall configure the AVL Data Collection Application......99
3.1.2.5.2 The IEC shall command the AVL Data Collection Application......99
3.1.3 The IEC shall interface with the VERITAS......99
3.1.3.1 ...... The IEC shall interface with the VERITAS IVE 99
3.1.3.2 ...... The IEC shall interface with the VERITAS IAE 99
3.1.3.3 ...... The IEC shall interface with the VERITAS VR-Forces AI 99
3.1.3.4 ...... The IEC shall interface with the VERITAS Data Logger 99
3.1.3.5 ...... The IEC shall interface with the HVD 99

3.1.3.5.1 The IEC shall configure the HVD terrain display at the start of a run 99
3.1.3.5.2 The IEC shall configure the HVD to display the correct entity location 99
3.1.4 The IEC shall interface with the CADWALL 99
3.1.4.1 ..... The IEC shall interface with the CADWALL Visualization 100
3.1.4.2 ..... The IEC shall interface with the CADWALL IAE 100
3.1.5 The IEC shall interface with the Operator Station 100
3.1.5.1 ..... The IEC shall interface with the Operator Station Visualization 100
3.1.6 The IEC shall manage experiment runtime state 100
3.1.6.1 ..... The IEC shall configure components in Idle state 100
3.1.6.2 ..... The IEC shall monitor status of components in Running Trial state 100
3.1.6.3 ..... The IEC shall monitor the status of components in Demo state 100
3.1.6.4 ..... The IEC shall recover from any errors and put the system in the Idle state 100
3.1.7 The IEC shall coordinate shutdown of all components 100
3.2 Usability 100
3.2.1 The IEC shall be usable with 2 hours training 100
3.2.2 The IEC shall enable a user to configure an existing experiment in 5 minutes 100
3.2.3 The IEC shall enable a user to configure a new experiment in 1 hour 100
3.2.4 The IEC shall provide the user with meaningful configuration error information 101
3.2.5 The IEC shall conform to standard Windows interface design guidelines 101
3.3 Performance 101
3.3.1 The IEC shall display all system component errors within 1s 101
3.3.2 The IEC shall be able to run all IVP systems simultaneously 101
3.3.3 The IEC shall be able to monitor all IVP systems simultaneously 101
3.4 Supportability 101
3.4.1 The IEC configuration file shall be in a custom XML format 101
3.4.2 The IEC GUI shall be based on MFC 101
3.4.3 The IEC code shall follow the project coding standards 101
3.5 Design Constraints 101
3.5.1 The IEC shall be developed using C++ 101
3.5.2 The IEC shall be developed using Microsoft VS2008 102
3.5.3 The IEC GUI shall be based upon MFC 102
3.5.4 The IEC shall use the MAK VR-Link library 102
3.5.5 The IEC shall use the MAK VR-Forces remote API 102
3.5.6 The IEC shall support communications using DIS 102
3.5.7 The IEC shall support communications using HLA 102
3.6 On-line User Documentation and Help System Requirements 102
3.7 Purchased Components 102
3.7.1 The IEC shall use the MAK RTI 102
3.7.2 The IEC shall use the MAK remote API 102
3.8 Interfaces 102
3.8.1 User Interfaces 102
3.8.1.1 ..... The IEC shall have an iSpace configuration user interface 102
3.8.1.2 ..... The IEC shall have a CAVE configuration user interface 103
3.8.1.3 ..... The IEC shall have an experiment configuration user interface 104
3.8.1.4 ..... The IEC shall have a CADWALL configuration user interface 105
3.8.1.5 ..... The IEC shall have a Operator Station configuration user interface 106
3.8.1.6 ..... The IEC shall have a Data Logger configuration user interface 106
3.8.1.7 ..... The IEC shall have a Demonstration user interface 106
3.8.1.8 ..... The IEC shall have a IVP status user interface 106
3.8.1.9 ..... The IEC shall have an Experiment Runtime interface 107
3.8.1.10 The IEC shall have a Scenario Block Runtime interface 107
3.8.2 Software Interfaces 107
3.8.2.1 ..... The IEC shall use the MAK remote API to communicate with MAK VR-Forces 107
3.8.2.2 ..... The IEC shall use the MAK remote API to communicate with the MAK Data Logger 107

3.8.3 Communications Interfaces..107
3.8.3.1 .... The IEC shall receive all DIS/HLA messages used by the system107
3.8.3.2 .... The IEC shall communicate with the system components using customs PDUs107

APPENDIX A: DEFINITIONS, ACRONYMS AND ABBREVIATIONS USED 107

1 Introduction

1.1 Overview

The Integrated Virtual Platform (IVP) Experiment Controller (IEC) is the executive for the IVP system. It will enable the user to control the IVP for an experiment including configuring and launching the appropriate components of the IVP, maintaining status on the operation of the IVP components, and shutting down the IVP.

1.2 Purpose

This SRS fully describes the external behavior of the IEC. It also describes nonfunctional requirements, design constraints, and other factors necessary to provide a complete and comprehensive description of the requirements for the IEC.

1.3 Scope

This SRS provides a high level view of the operation of the IEC from the user perspective. This should enable users get a view on how the software will control an IVP experiment and what kinds of control and configuration are available. Further sections of the document will provide increasing detail on the requirements for developers to use to create a design for the IEC.

1.4 Structure and Organization of This Document

Section 2 provides a high level view of the operation of the IEC. Section 3 details the specific requirements that flow from the high level operational description.

2 Overall Description

The IEC will function as the high level coordinator of the systems of the IVP in order to execute experiments. The IVP is a system of systems that enables multiple participants to interact inside of the same virtual environment. The IVP is composed of the AVL iSpace, VERITAS CAVE, CADWALL, and the Operator Station. Both the iSpace and CAVE are multi-wall immersive virtual environments, while the CADWALL is a very large screen based display. The Observer station is a workstation based display. An experiment is composed of any or all of these systems and their respective selected components, the system operators, a common virtual environment, a set of experiment execution instructions, and the experiment data collection parameters.

The IVP contains the following systems and components:

1. iSpace – immersive system
    a. Integrated Virtual Environment (IVE) – visualization of the virtual environment and user input using Wand or Flystick
    b. Integrated Audio Environment (IAE) – 3D spatialized audio environment
    c. VR-Forces AI – artificial intelligence engine for all non-participant entities in the virtual environment
    d. Stealth Viewer – virtual environment viewer
    e. Data Logger – DIS message logging and playback
2. CAVE – immersive system
    a. IVE - visualization of the virtual environment and user input using Wand or Joystick
    b. IAE – 3D spatialized audio environment
    c. VR-Forces AI - artificial intelligence engine for all non-participant entities in the virtual environment
    d. Data Logger – DIS message logging and playback

    e. Handheld Visual Display (HVD) – visual compass and map display for PJ
3. CADWALL – Very Large Visual Display
    a. Visualization
    b. IAE - 3D spatialized audio environment
4. Observer Station – workstation based display
    a. Visualization

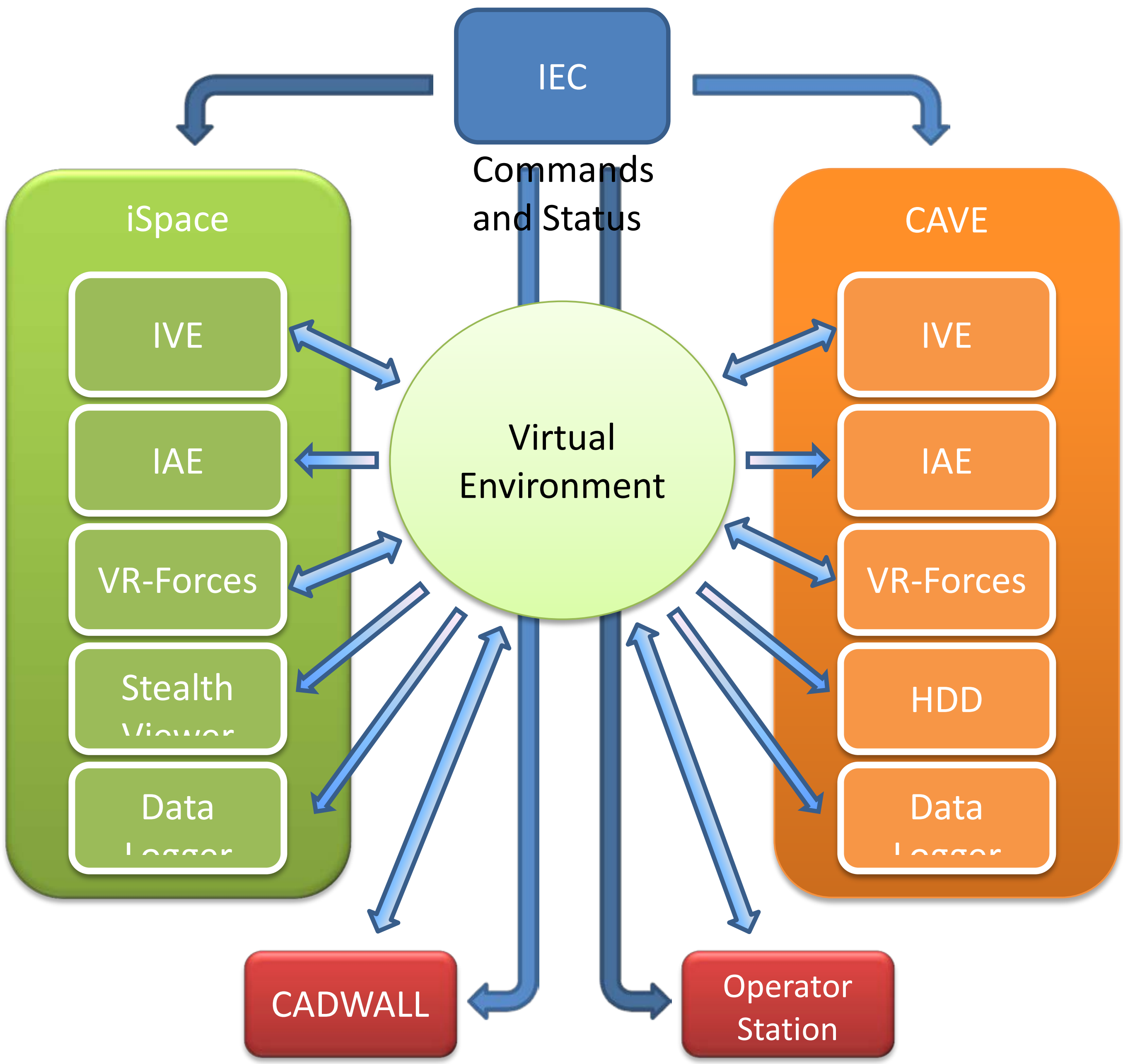


Figure 20: IVP System Architecture

The IEC will have a communication channel with each of the four main systems. The four systems in turn communicate with the IEC and also share data to maintain a common state of the virtual

environment. The IVP system uses either DIS or HLA as the means by which the systems pass messages to maintain the virtual environment state. The IEC communications channel will be a virtual communications channel created inside the DIS or HLA data channel using custom PDUs.

The experiment creator must choose which IVP systems to enable for a particular experiment and then decide which components of each system are appropriate. There are constraints on which components are valid depending upon which systems are enabled. For example, only one VR-Forces or Data Logger can be enabled for an experiment. All enabled components must be configured differently depending on the role of the system in the experiment.   Each system must obey scenario control commands such as initialize, start, stop, pause and exit. Further complicating the configuration problem for the experimenter is the need for the components to be initialized in an experiment dependent order. This initialization order also includes instructions for the experimenter to perform actions like putting the participant in the CAVE that can’t be performed automatically. The IEC must support some degree of variable initialization order and instructions to the experiment so that multiple experiments can be supported with a minimum of additional programming effort.

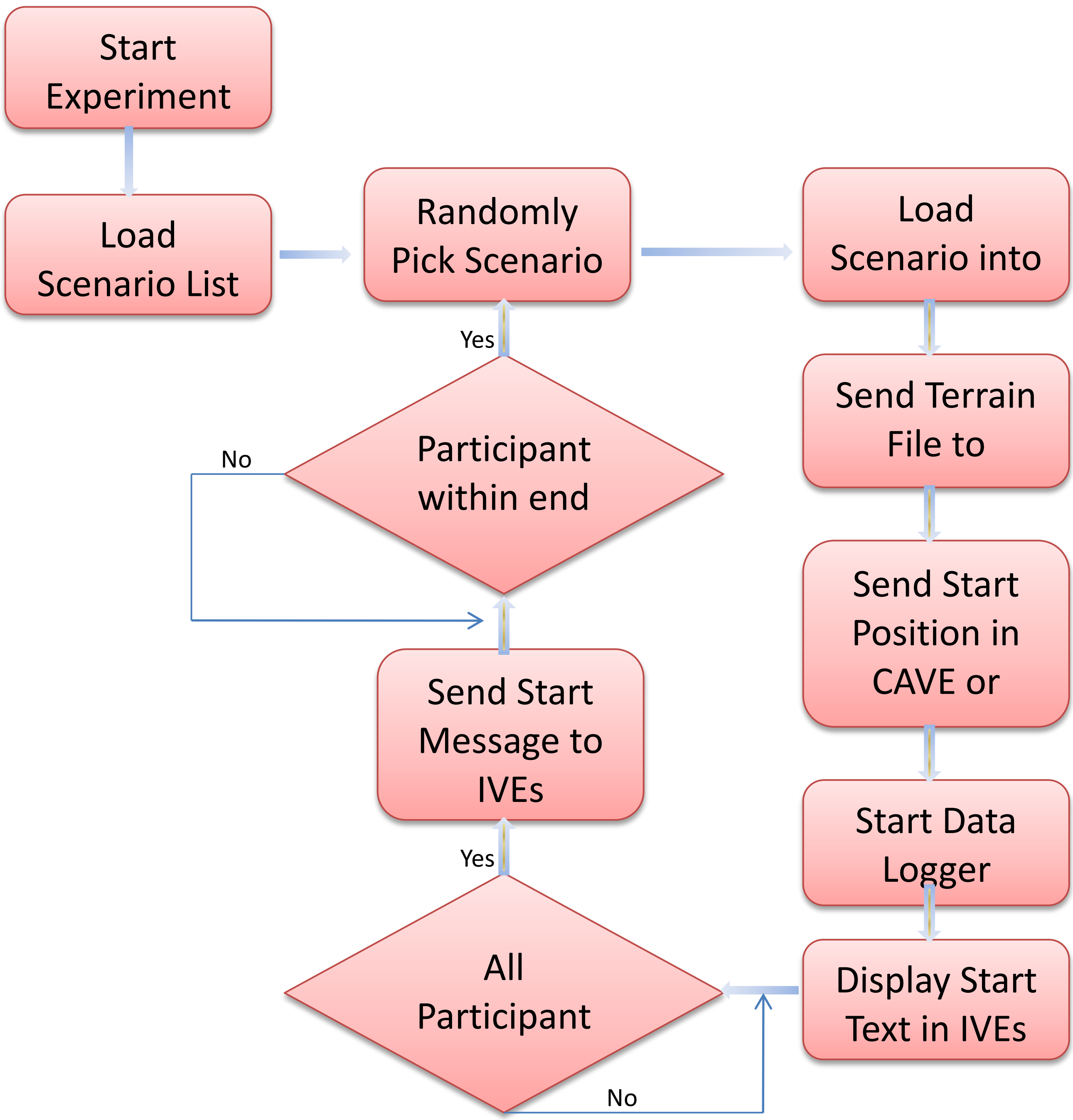


Figure 21 : Representative IEC Experiment States

The Representative IEC Experimental States flow chart is a high level view of the states for a notional experiment run from the point of view of the IEC. However, to support a broad range of experimental configurations the IEC will need to support a limited scripting of experiments. This is necessary because each experiment is different in its execution order due to differences in equipment configuration, interactions with the participant, and configuration of supporting software applications. The IEC must also be able to display experimenter prompts to guide execution of experiments. A means of varying the startup sequence of the components in conjunction with the instruction sequence will support a wide variety of experimental configurations. The repeating execution loop of the experiment reflects running a

participant through a block of trials composed of different terrain and threats so the IEC must also be able to maintain a list of the scenarios for a particular block of trials.

The IEC provides a solution to the experimental configuration, execution and system dependency problems that exist in the IVP. It will be a single interface to select systems for demonstrations or experiments, configure the components of the systems and establish the execution order of experiments. Experimental configurations can easily be saved and restored. During an experiment's execution, the IEC will aid the experimenter by providing execution prompts and monitoring the status of the systems. Data collection will be automatically configured so that all data for a trial is saved in a coherent manner.

3 Specific Requirements

The IEC specific requirements are divided into functional requirements, usability requirements, performance requirements, supportability requirements, design constraints, documentation requirements, purchased components and interface requirements.

3.1 Functionality

The IEC's main purpose is to allow the establishment of experimental configurations, establishing the order of initialization of components, providing sequencing of instructions and execution of commands during experiments. Creating, saving, loading and executing these different experiments in an easy to use manner that aids the experimenter defines the highest level requirement for the IEC.

The IEC will perform four basic tasks for the components of the systems:

1. Lanuch the component
2. Configure the component
3. Command the component
4. Monitor the status of the component

A requirement to perform each of the four tasks will be listed for each component. Following this, any component specific aspects of these four tasks will be listed as sub-requirements. Because many of the components are third party applications, in many cases it is not possible to have the fine level of control one might desire over the components behavior. Regardless of the level of support that a particular component might provide for implementing an IEC requirement, the requirement will be listed to show what the desired behavior would be.

In general, the IEC will configure the components by copy any necessary configuration files to the appropriate directory and automatically launching the application if possible.
Commanding components from the IEC will be restricted to Launch, Kill, Initialize, Start, Pause, Stop and Terminate commands. These commands are sent over a virtual command channel that will utilize the existing DIS/HLA communications channel to distribute the commands.

The IEC will issue specific commands to components in order to execute a particular. These specific commands are listed are listed as detailed requirements. Additionally, in certain states the IEC must wait for specific event messages from components.

3.1.1 The IEC shall allow the user to create an experiment sequence

The experiment sequence is an ordered sequence composed of instructions, commands and a scenario list.

3.1.1.1 The IEC shall allow the user to add, edit and delete instruction steps from an experiment sequence

The instructions are composed of a text file and optional image to display to the experimenter during experiment execution.

3.1.1.2 The IEC shall allow the user to add, edit and delete commands from an experiment

The commands available to the user are defined in the detailed requirements for each component. In general, each component should support at least launch and terminate. The IVE supports the most specific commands due to its unique role as the interface between the participant and the system.

3.1.1.3 The IEC shall allow the user to add edit and delete scenarios from an experiment

A scenario entry is composed of the terrain file, the VF-Forces scenario file and the start position of the participant in the terrain.

3.1.2 The IEC shall interface with the AVL

The IEC shall be able to enable and disable the use of the entire AVL system for an experiment or demonstration. This is controllable during experiment definition by the user and set by the experiment configuration file during an experiment run. Demonstration mode will also allow dynamic enable/disable of the entire AVL system.

3.1.2.1 The IEC shall interface with the AVL iSpace IVE

The IEC will be configured with the main system ID and IP address of the IVE in the iSpace cluster. The default configuration information must be editable through the registry. This information must be editable in the interface and stored with the experiment definition file.

3.1.2.1.1 The IEC shall configure the iSpace IVE

The iSpace IVE requires the file locations for the Main and Location ACF file. These files provide the parameters for the visual scene rendering and the input devices. The iSpace IVE also requires an initial state to be set and an initial location for the viewpoint during initialization for a demo or experiment run.

3.1.2.1.1.1 The IEC shall set the IVE initial state

The IVE initial state can be READY, PRE_TRIAL, or RUN_TRIAL. By default the IVE starts in PRE_TRIAL. The IEC can command the IVE to change to RUN_TRIAL from PRE_TRIAL, or to PRE_TRIAL from RUN_TRIAL.

3.1.2.1.1.2 The IEC shall set the IVE start location

The IVE start location is a (X, Y, Z) position and (h, p, r) orientation. The IEC shall send a custom PDU to the IVE in order to set the start location an orientation.

3.1.2.1.1.3 The ICE shall set the IVE main ACF file

The IVE main ACF contains all of the common data for each immersive space. The IEC shall send a custom PDU to the IVE containing the file name of the main ACF file to load.

3.1.2.1.1.4 The IEC shall set the IVE location ACF file

The IVE location ACF file contains all of the location specific data for the immersive space such as input devices.

3.1.2.1.2 The IEC shall command the iSpace IVE

The IEC shall issue the standard commands of initialize, start, pause, stop and exit to control the iSpace IVE. All of these commands are sent via the HLA/DIS link through custom PDUs.

3.1.2.1.2.1 The IEC shall set the IVE observer position

The IEC shall command the IVE to move the participant location to a new (X,Y,Z) position and (h, p, r) orientation.

3.1.2.1.2.2 The IEC shall request the current IVE configuration ACF file name

The IEC shall send a custom PDU to the IVE requesting the name of the IVE's current ACF file. The IEC shall respond with a custom PDU containing the ACF file name.

3.1.2.1.2.3 The IEC shall command the IVE to load a terrain database

The IEC shall send a custom PDU containing the name of a terrain database to load. This causes the IVE to load the new terrain.

3.1.2.1.2.4 The IEC shall command the IVE to set the time of day of the environment

The IEC shall send a custom PDU to the IVE to set the time of day.

3.1.2.1.2.5 The IEC shall command the IVE to set the weather in the environment

The IEC shall send a custom PDU to the IVE to change the weather in the environment. The valid values are clear, scattered or overcast.

3.1.2.1.2.6 The IEC shall command the IVE to display text

The IEC shall command the IVE to display text on the front wall by sending a custom PDU with the text to be rendered.

3.1.2.1.2.7 The IEC shall command the IVE to exit

The IEC shall send a custom PDU to the IVE commanding it to exit. The IVE shall shutdown upon receiving the command.

3.1.2.1.2.8 The IEC shall command the IVE to start a trial

The IEC shall command the IVE to start a trial using a custom PDU. If the IVE is in READY or PRE+_TRIAL state, the IVE shall change its state to RUN_TRIAL.

3.1.2.1.2.9 The IEC shall command the IVE to stop a trial

The IEC will send command the IVE to stop a trial using a custom PDU. If the IVE is in RUN_TRIAL state the IVE will change its state to PRE_TRIAL. If the IVE is not in RUN_TRIAL state no action is taken.

3.1.2.1.3 The IEC shall monitor the status of the AVL iSpace IVE

The IEC will monitor the status of the IVE to the maximum extent possible. The status of the IVE (READY, PRE_TRIAL, RUN_TRIAL) shall be displayed in the interface of the IEC. Any command acknowledgements from the IVE will be displayed in the IEC.

3.1.2.2 The IEC shall interface with the iSpace IAE

The IEC will be configured with the system ID and IP address of the IAE in the iSpace. This configuration information must be editable through the registry.

3.1.2.2.1 The IEC shall configure the iSpace IAE

The IEC shall provide the IAE configuration file name for the run.

3.1.2.2.2 The IEC shall command the iSpace IAE

The IAE needs to support the basic commands of initialize, start, pause, stop and exit.

3.1.2.2.3 The IEC shall monitor the status of the iSpace IAE

Note: there is no status available for the IAE. The IAE should be able to send replies to configuration status, runtime status and command acknowledgment.

3.1.2.3 The IEC shall interface with the AVL VR-Forces AI

The VR-Forces Remote Control API is used to interface with VR-Forces. Note the only one VR-Forces AI, either the iSpace or VERITAS, may be active for a particular experiment.

3.1.2.3.1 The IEC shall configure the AVL VR-Forces AI

The IEC shall provide the name of the configuration file for the VR-Forces AI.

3.1.2.3.2 The IEC shall command the AVL VR-Forces AI

The IEC needs to provide at least the initialize, start, stop, pause and exit commands if possible.

3.1.2.3.3 The IEC shall monitor the status of the AVL VR-Forces AI

TBD: determine what status is available from the VR-Forces AI interface.

3.1.2.4 The IEC shall interface with the AVL Stealth Viewer

The IEC should be able to remotely launch the Stealth Viewer. There is no practical interface with the actual application.

3.1.2.4.1 The IEC shall configure the AVL Stealth Viewer

There is no configuration for the AVL Stealth Viewer.

3.1.2.4.2 The IEC shall command the AVL Stealth Viewer

There is no command interface in the Stealth Viewer.

3.1.2.5 The IEC shall interface with the AVL Data Collection Application

The Data Collection Application will be a new application that supplements the data collection performed by the MAK Data Logger. Note that only one Data Logger, either the iSpace or the VERITAS, may be active for a particular experiment. The Data Collection Application shall support the IEC initialize, start, pause, stop, and exit commands. The Data Collection Application will also support status messages to the IEC.

3.1.2.5.1 The IEC shall configure the AVL Data Collection Application

TBD: The configuration interface is under development.

3.1.2.5.2 The IEC shall command the AVL Data Collection Application

TBD: The command interface is under development.

3.1.3 The IEC shall interface with the VERITAS

The IEC shall be able to enable and disable the use of the entire VERITAS system for an experiment or demonstration. This is controllable during experiment definition by the user and set by the experiment configuration file during an experiment run. Demonstration mode will also allow dynamic enable/disable of the entire VERITAS system.

3.1.3.1 The IEC shall interface with the VERITAS IVE

The IEC interfaces with the VERITAS IVE in the same manner as the iSpace IVE detailed above.

3.1.3.2 The IEC shall interface with the VERITAS IAE

The IEC interfaces with the VERITAS IAE in the same manner as the iSpace IAE detailed above.

3.1.3.3 The IEC shall interface with the VERITAS VR-Forces AI

The IEC interfaces with the VERITAS VR-Forces AI in the same manner as the iSpace VR_Forces AI detailed above. Note the only one VR-Forces AI, either the iSpace or VERITAS, may be active for a particular experiment.

3.1.3.4 The IEC shall interface with the VERITAS Data Logger

The IEC interfaces with the VERITAS Data Logger in the same manner as the iSpace Data Logger detailed above. Note that only one Data Logger, either the iSpace or the VERITAS, may be active for a particular experiment.

3.1.3.5 The IEC shall interface with the HVD

The HVD is a handheld computer at the CAVE. It acts as a visual compass and map display for the PJ participant. The HVD is given a map file at the start of each scenario run. Interfacing is performed through the DIS/HLA network using custom messages.

3.1.3.5.1 The IEC shall configure the HVD terrain display at the start of a run

The HVD displays an image of the terrain with hostile marker, waypoint markers and an elevation line. The HVD listens to the DIS/HLA network for a terrain name.

3.1.3.5.2 The IEC shall configure the HVD to display the correct entity location

The HVD displays the current participant location. The HVD listens to the DIS/HLA network for the current location information.

3.1.4 The IEC shall interface with the CADWALL

TBD– need detail here, description of what functions the CADWALL is supposed to fulfill. Will it be a MMD, or other application?

3.1.4.1 The IEC shall interface with the CADWALL Visualization

TBD – need detail here

3.1.4.2 The IEC shall interface with the CADWALL IAE

TODO – need detail here

3.1.5 The IEC shall interface with the Operator Station

The operator station is currently the VR-Forces GUI, which monitors the Virtual Environment's state and allows the operator to insert voice cueing and control the experiment run.

3.1.5.1 The IEC shall interface with the Operator Station Visualization

The IEC does not have means to interface with the VR-Forces GUI at this time.

3.1.6 The IEC shall manage experiment runtime state

There are three basic states – READY, PRE_TRIAL, and RUN_TRIAL.

3.1.6.1 The IEC shall configure components in Idle state

The IEC should be able to configure components in the pre-trial state, but once the system is actually running a trial or demo, the IEC shall have the configuration disabled.

3.1.6.2 The IEC shall monitor status of components in Running Trial state

3.1.6.3 The IEC shall monitor the status of components in Demo state

3.1.6.4 The IEC shall recover from any errors and put the system in the Idle state

3.1.7 The IEC shall coordinate shutdown of all components

All components must eventually be modified to support a coordinated clean shutdown procedure. This is not a current capability of the system components.

3.2 Usability

The IEC has minimum usability requirements that must be met. The purpose of these requirements is to enable a user with moderate training to be able configure and run experiments or demonstrations of the software within reasonable time requirements.

3.2.1 The IEC shall be usable with 2 hours training

The IEC shall be usable by a person familiar with the elements of the system, the basic requirements to configure the system elements and the experimental execution parameters with two hours training.

3.2.2 The IEC shall enable a user to configure an existing experiment in 5 minutes

A trained user shall be able to modify the run parameters (block number, experiment number, trial number) and other trial specific parameters with 5 minutes in preparation for the next trial

3.2.3 The IEC shall enable a user to configure a new experiment in a day

A trained user should be able to select the components for an experiment, configure the components and set up the parameters of the experiment within one day.

3.2.4 The IEC shall provide the user with meaningful configuration error information

The IEC shall detect configuration errors entered by the user and provide meaningful information on the type and resolution of the error.

3.2.5 The IEC shall conform to standard Windows interface design guidelines

The IEC should conform to all standard Windows interface guidelines.

3.3 Performance

The IEC must be able to handle the most complex configurations of the IVP and a bounded number of non-participant entities in the virtual environment. The runtime and configuration status of each component of the IVP systems must be available to the user at all times.

3.3.1 The IEC shall display all system component errors within 1s

None of the systems or their components has the ability to notify the IEC of errors. In the future the command channel should be used to propagate error messages from a component to the IEC.

3.3.2 The IEC shall be able to run all IVP systems simultaneously

All available systems and an appropriate selection of components should be able to be run simultaneously. There must not be hidden dependencies on what can and can't be run together.

3.3.3 The IEC shall be able to monitor all IVP systems simultaneously

The IEC shall monitor all of the enabled systems simultaneously and display the status of the systems in the GUI.

3.4 Supportability

The IEC has requirements that enhance the supportability and maintainability of the system, including coding standards, naming conventions, and class libraries.

3.4.1 The IEC configuration file shall be in a custom XML format

A custom XML format reflecting the available configuration items for the IVP will be developed. The IEC shall use this custom XML format to save configurations. The IEC shall also read files using the custom XML format in order to configure the IEC.

3.4.2 The IEC GUI shall be based on MFC

The MFC libraries will provide all of the basic GUI functionality for the IEC. The use of MFC will enhance the supportability of the IEC.

3.4.3 The IEC code shall follow the project coding standards

For consistency, the development team must agree on and use a common coding standard.

3.5 Design Constraints

The IEC has the following design constraints. These constraints represent design decisions that have been mandated and must be adhered to.

3.5.1 The IEC shall be developed using C++

C++ will be the standard language for the IEC.

3.5.2 The IEC shall be developed using Microsoft VS2008

Microsoft VS2008 is being used for the IAE and IEC.

3.5.3 The IEC GUI shall be based upon MFC

MFC shall provide the basic windows and control capability required for the interface of the IEC.

3.5.4 The IEC shall use the MAK VR-Link library

The MAK VR-Link library provides the connectivity through HLA or DIS.

3.5.5 The IEC shall use the MAK VR-Forces remote API.

The MAK VR-Forces remote API allows the IEC to configure the VR-Forces component.

3.5.6 The IEC shall support communications using DIS

3.5.7 The IEC shall support communications using HLA

3.6 On-line User Documentation and Help System Requirements

The IEC shall contain access to all online documentation contained in the WSU IVP wiki.

3.7 Purchased Components

The IEC will use purchased components to provide necessary functionality.

3.7.1 The IEC shall use the MAK RTI

3.7.2 The IEC shall use the MAK remote API

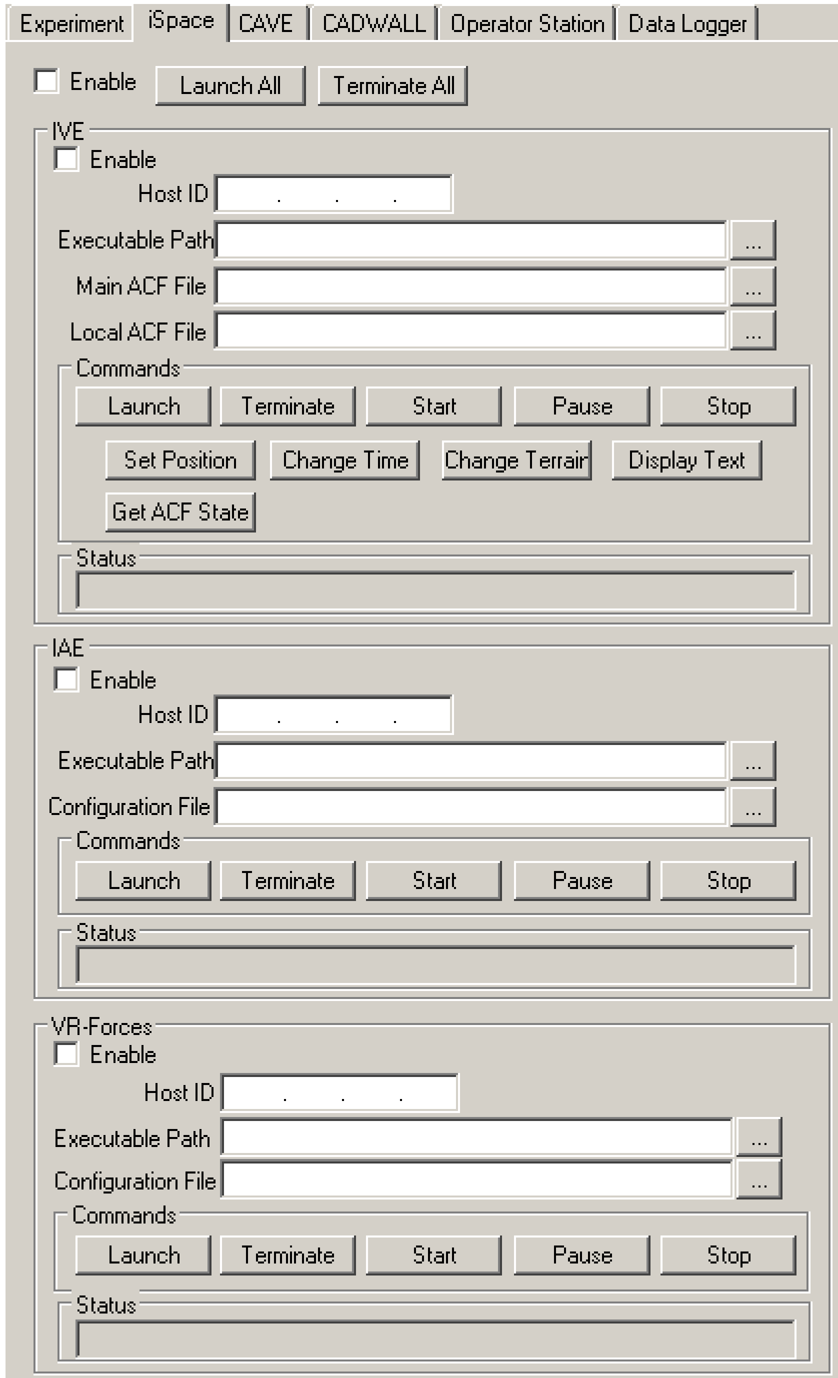
3.8 Interfaces

The IEC supports multiple interfaces with the user and various system and components of the IVP.

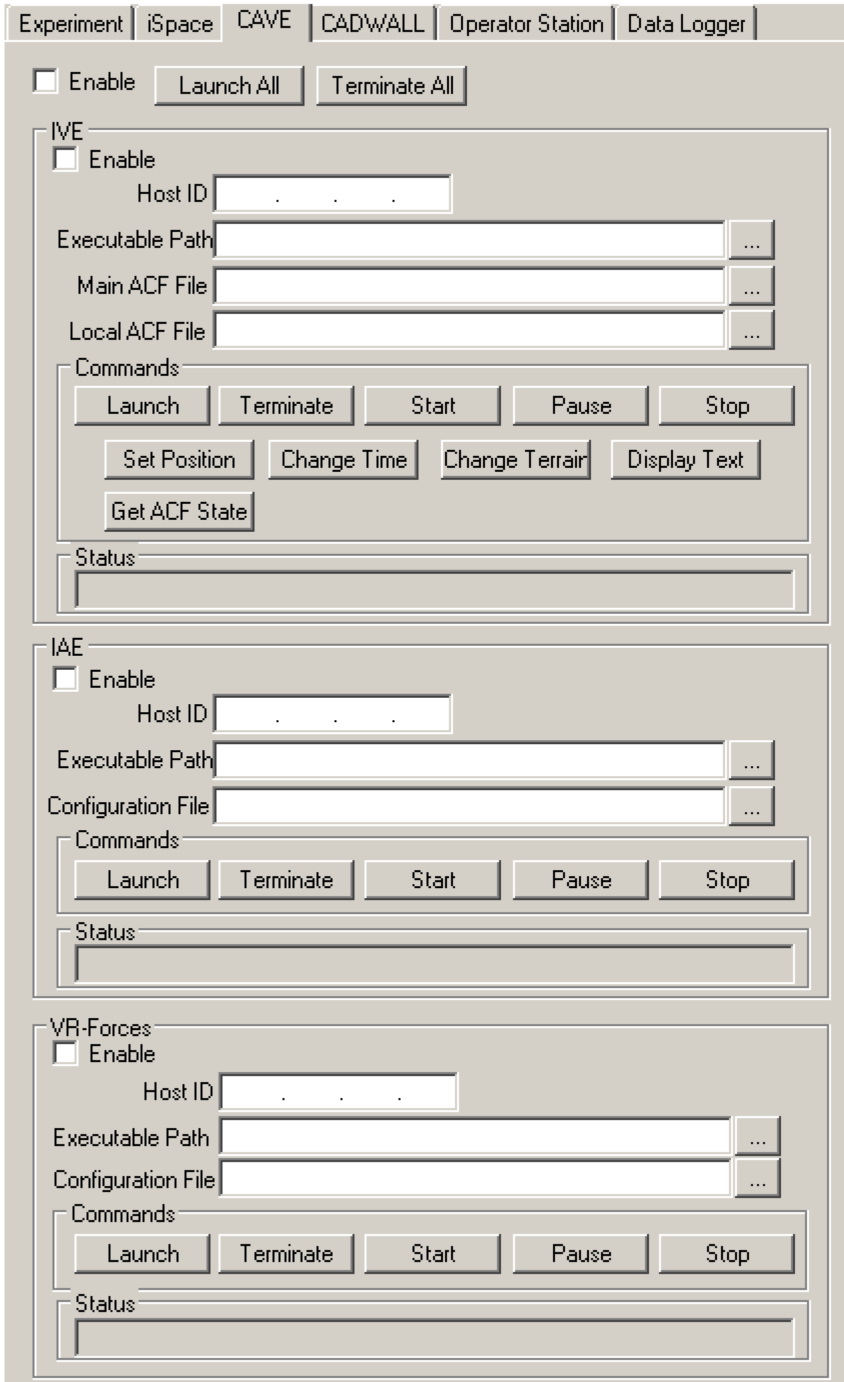
3.8.1 User Interfaces

The IEC shall support multiple user interface displays to select, configure and display the status of the components of the IVP.

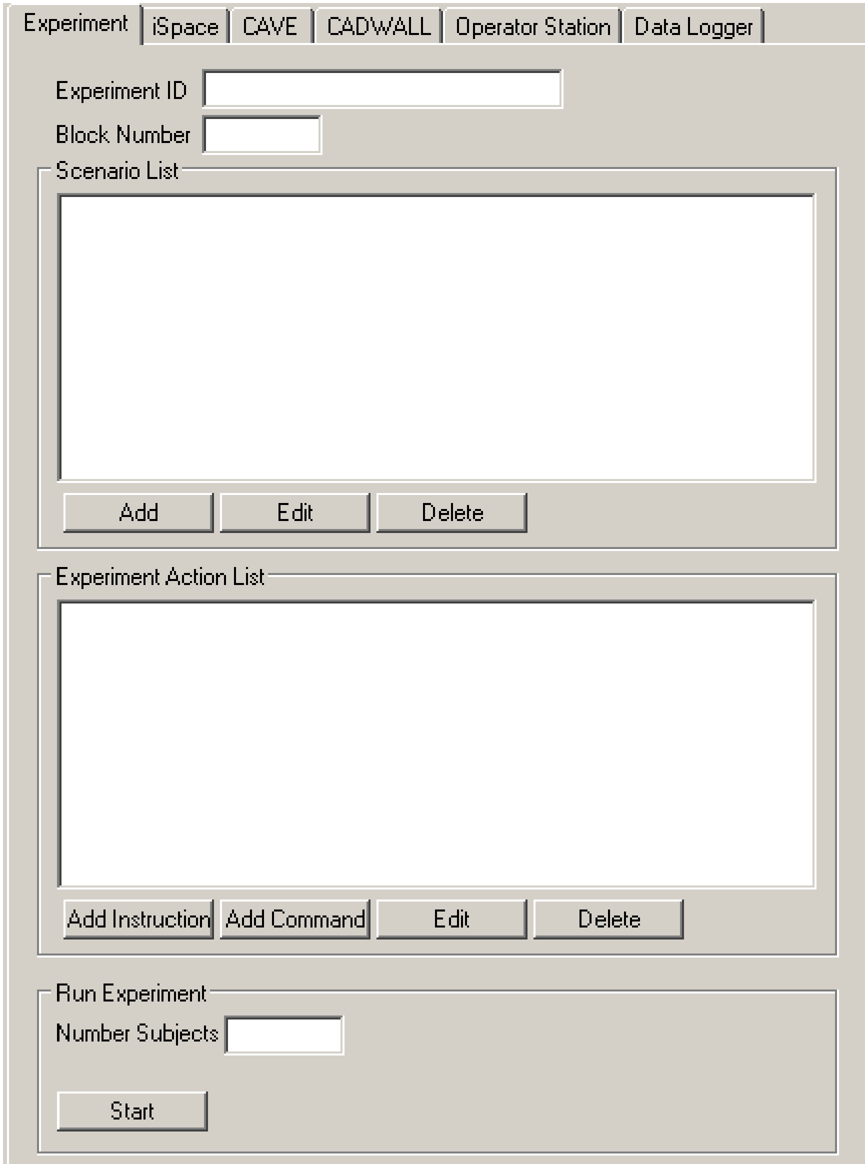
3.8.1.1 The IEC shall have an iSpace configuration user interface



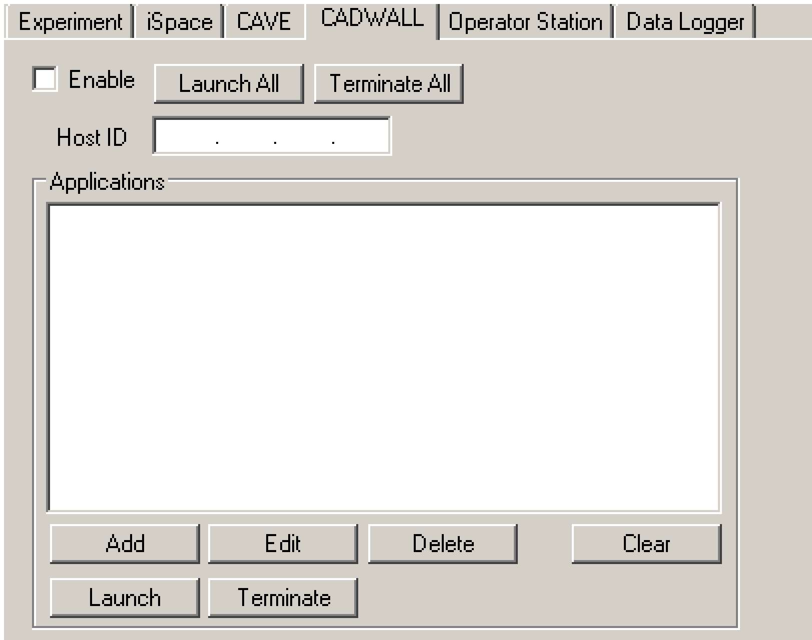
3.8.1.2 The IEC shall have a CAVE configuration user interface



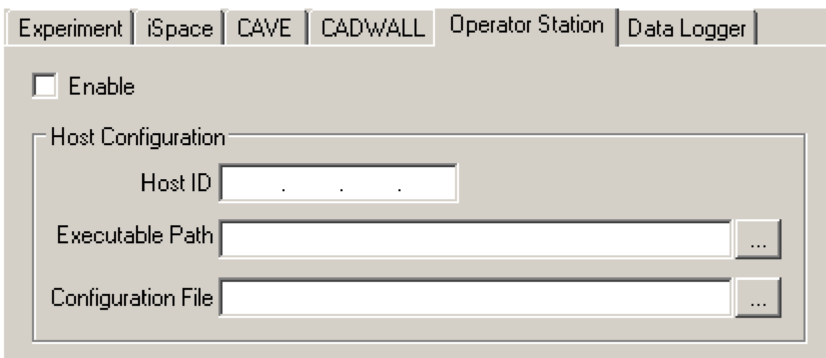
3.8.1.3 The IEC shall have an experiment configuration user interface



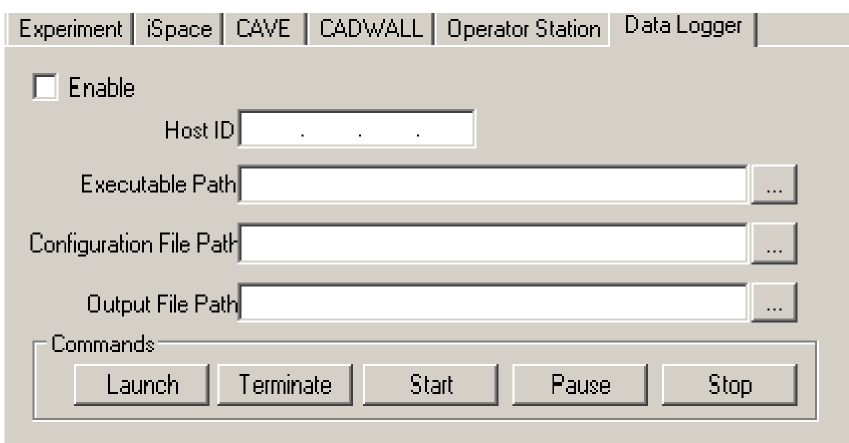
3.8.1.4 The IEC shall have a CADWALL configuration user interface



3.8.1.5 The IEC shall have a Operator Station configuration user interface



3.8.1.6 The IEC shall have a Data Logger configuration user interface



3.8.1.7 The IEC shall have a Demonstration user interface

The demonstration user interface is contained in the individual systems user interfaces.

3.8.1.8 The IEC shall have a IVP status user interface

The IVP systems status is contained in the individual systems components user interface sections.

3.8.1.9 The IEC shall have an Experiment Runtime interface

3.8.1.10 The IEC shall have a Scenario Block Runtime interface

3.8.2 Software Interfaces

3.8.2.1 The IEC shall use the MAK remote API to communicate with MAK VR-Forces

3.8.2.2 The IEC shall use the MAK remote API to communicate with the MAK Data Logger

3.8.3 Communications Interfaces

3.8.3.1 The IEC shall receive all DIS/HLA messages used by the system

3.8.3.2 The IEC shall communicate with the system components using customs PDUs

The custom PDUs used by the IEC and the system components will be detailed in the Command and Data ICD.

Appendix A: Definitions, Acronyms and Abbreviations Used

- IVP – Integrated Virtual Platform is the name for the system of systems to allow multiple participants to interact in the same virtual environment.
- IVE – Integrated Virtual Environment is the CAVE component of the iSpace and VERITAS systems.
- IEC – IVP Experiment Controller
- IAE – Integrated Audio Environment is the 3D spatialized audio component of the iSpace and VERITAS systems.
- HMD – Head Mounted Display is a display device worn on the head. In the case of the iSpace and VERITAS it is a pair of shutter glasses.
- DIS – Distributed Interactive Simulations is an open standard for conducting platform level simulations.
- HLA – High Level Architecture is a general purpose architecture for distributed simulation systems
- MFC – Microsoft Foundation Classes is a class library used for creating Windows applications
- MSVS2008 – Microsoft Visual Studio 2008 is the development environment for the software.
- PDU – Protocol Description Unit
- GUI – Graphical User Interface
- XML – eXtensible Markup Language
- VR-Forces – MAK software package for AI control of non-participant entities
- Data Logger – MAK software package for logging all DIS/HLA traffic generated by the IVP.
- Slab3D – is a real-time virtual acoustic environment rendering system originally developed in the Spatial Auditory Displays Lab at NASA Ames Research Center.
- OpenFlight – MultiGen-Paradigm terrain database file format.

APPENDIX 3

Scenario Generation Utility
Requirements

Description -

The Scenario Generator Utility uses window location information from a terrain, the location of events, and mapping information for azimuth and elevation distribution to create a scenario configuration file. The scenario configuration file is used by the CAVE or iSpace to run a trial to run experiments on the use of spatial audio for threat indication. For each location, a threat location and a user defined number of distractor locations are chosen based upon the visibility, distance and mapping to the desired azimuths and elevation for the experiment. Once all of the threat and distractor locations for a scenario are determined, a XML file that is readable by the IEC is output as well as a summary text file so the experiment can be documented.

Inputs -

1. Window Information XML File containing hierarchical window information for each tile
    a. Tile Name -> Road -> Building ->Windows hierarchy for windows information
    b. Tile Name -> Road -> Building ->Walls for building wall information
    c. Windows level will have position and orientation for each window
    d. Walls level will have the location, orientation and extents for each wall
    e. All coordinates will be in untranslated and unrotated tile coordinates
2. Scenario Description
    a. 4 Tile Entries
        i. Name of Tile
        ii. Position of tile (1-4, mapped to 4 quadrants in x-y plane)
        iii. Orientation of tile (1-4, mapped to 0, 90, 180 and 270 rotations)
    b. Number of Trial Locations - integer number of following records
    c. Trial Location Information
        i. Tile for Location
        ii. Untransformed trial location (x,y)
        iii. Untransformed trial orientation (heading)
    d. Path Information
    e. Event location information
    f. File generation parameters
3. ALF Speaker Locations File
    a. One line for each possible speaker location in AZ and El

User Interface -

The configuration screen details the tiles available, the ALF locations configuration file and 4 by 4 terrains for each scenario. For each source tile, the user can define its ID, the source file name and the event locations for the tile. The event locations contain the un-translated and un-rotated coordinates of the event as well as the participants entry direction. The configuration page appears below.

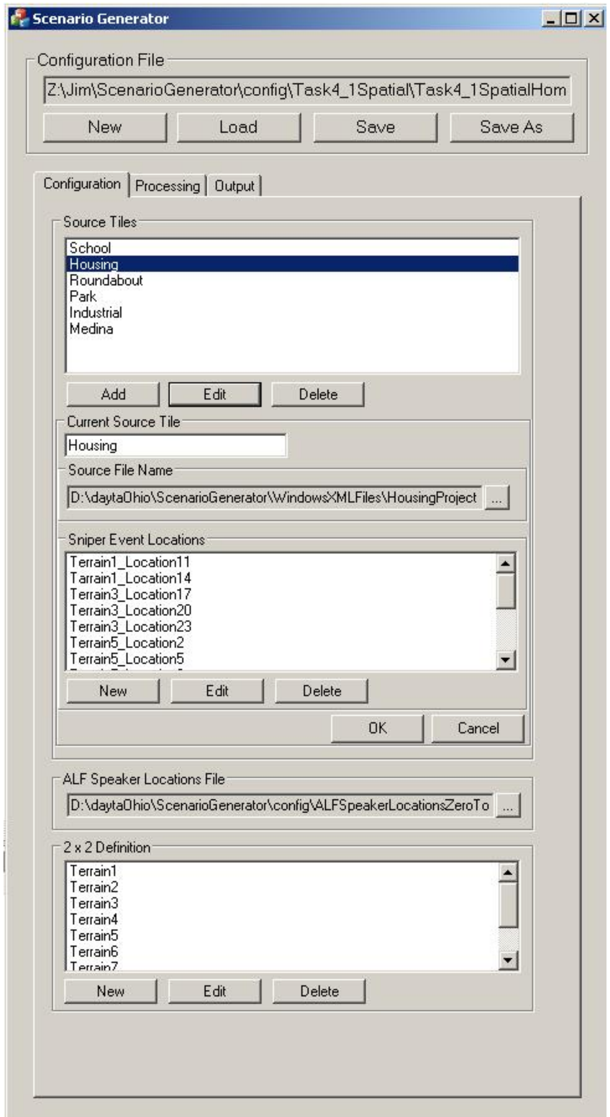


Figure 22: Configuration Page

Once the user has defined this information they can continue to the processing page. The processing page lets the user define the scenario path by selected the locations in the expected order of execution during a trial. In addition, several other parameters define the number of output files, the number of events per file, the maximum number of distractor locations, a maximum distance and angle parameter, the default sound file and the tolerance angle for acceptance as an ALF mapped window. The processing page appears below.

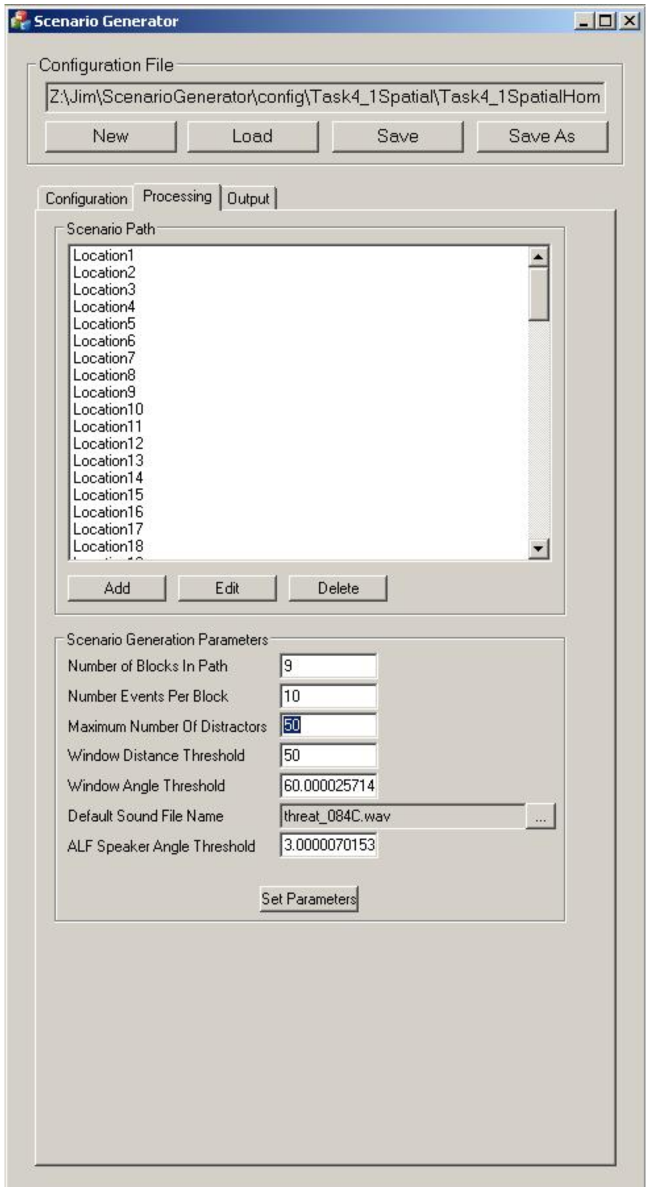


Figure 23: Processing Page

The output page allows the user to specify the base output file name and to review the parameters that have been entered for the scenario generation operation. Once the Generate Scenarios button is pressed the utility uses all of the information presented in the summary to create the scenario files. the Output Page appears below:

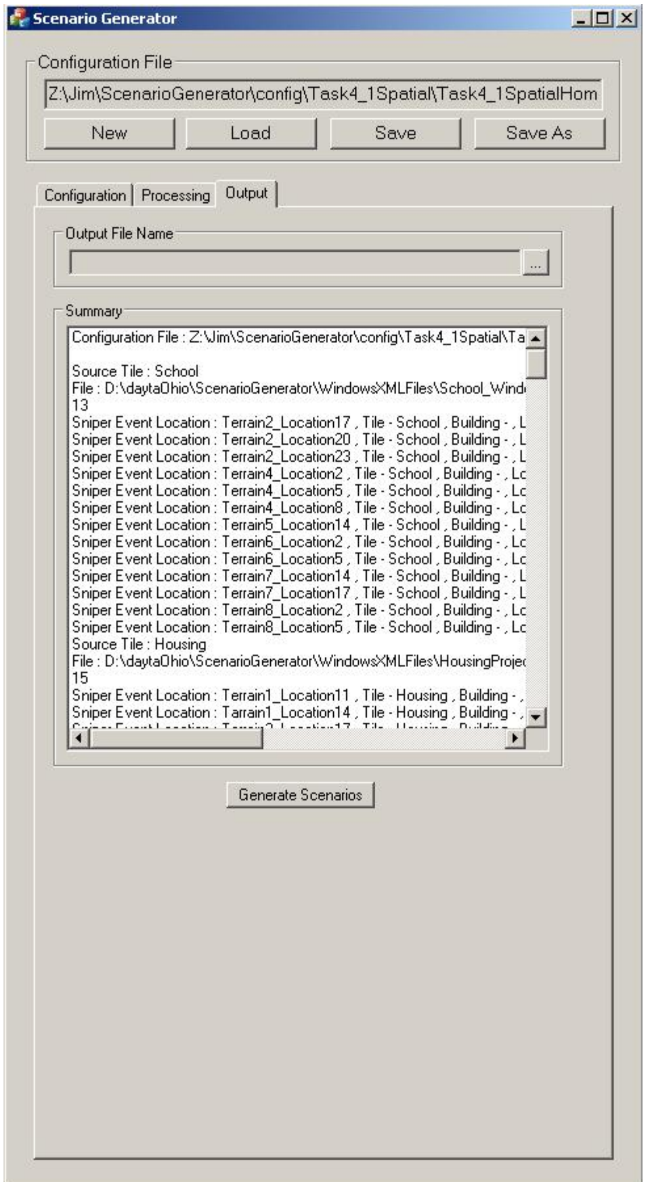


Figure 24: Output Page

Processing -

1. Program Reads in the Window Information file, Scenario Description File and ALF Speaker Locations file
2. For each tile in the Scenario Description File
    a. Create Transformed Windows information by applying defined translation and rotation to all entries in the hierarchy for the tile
3. For each Trial Location in the Scenario Description File
    a. Create Transformed Trial Location Entry by applying defined translation and rotation for appropriate tile to location and orientation
    b. Find all windows in LOS and within maximum distance from location
        i. Clip windows on distance
        ii. Clip windows on orientation
        iii. For each remaining window check LOS

            1. Create LOS vector from trial location to window
            2. For each wall
                a. Clip walls on distance
                b. Clip walls on orientation
                c. Find intersection of LOS vector and wall
                    i. if intersection is in bounds of wall, record wall and distance to intersection point
            3. Sort recorded wall intersections by distance
            4. If wall containing window is closest then window is in LOS and record window, otherwise discard
    c. Pick sniper location from windows in LOS
        i. Pick unduplicated ALF speaker location over all trial locations from possibilities in ALF Speaker Locations File
        ii. Find closest window to picked speaker azimuth and elevation
        iii. If no window within tolerance, try again
    d. Pick *n* distractor locations from windows is LOS
        i. Pick unduplicated ALF speaker location from this trial from possibilities in ALF Speaker Locations File
        ii. Find closest window to picked speaker azimuth and elevation
        iii. If no window within tolerance, try again

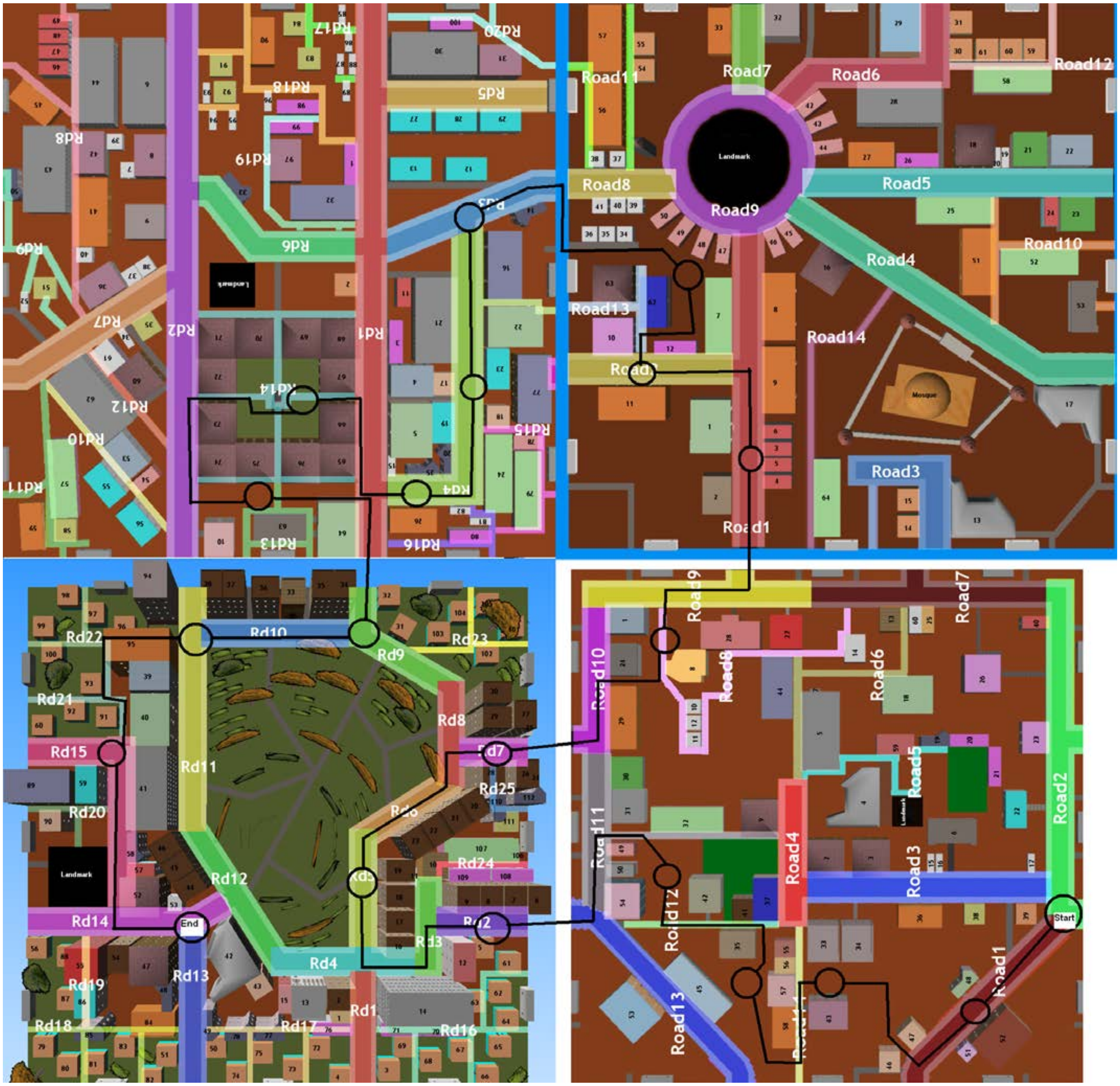
Outputs -

1. XML file containing all processing results
    a. Number of trial locations
    b. For each trial location
        i. All transformed coordinates for windows in LOS
        ii. Transformed trial location coordinates
        iii. Transformed sniper window coordinates
        iv. All transformed distractor window coordinates

APPENDIX 4

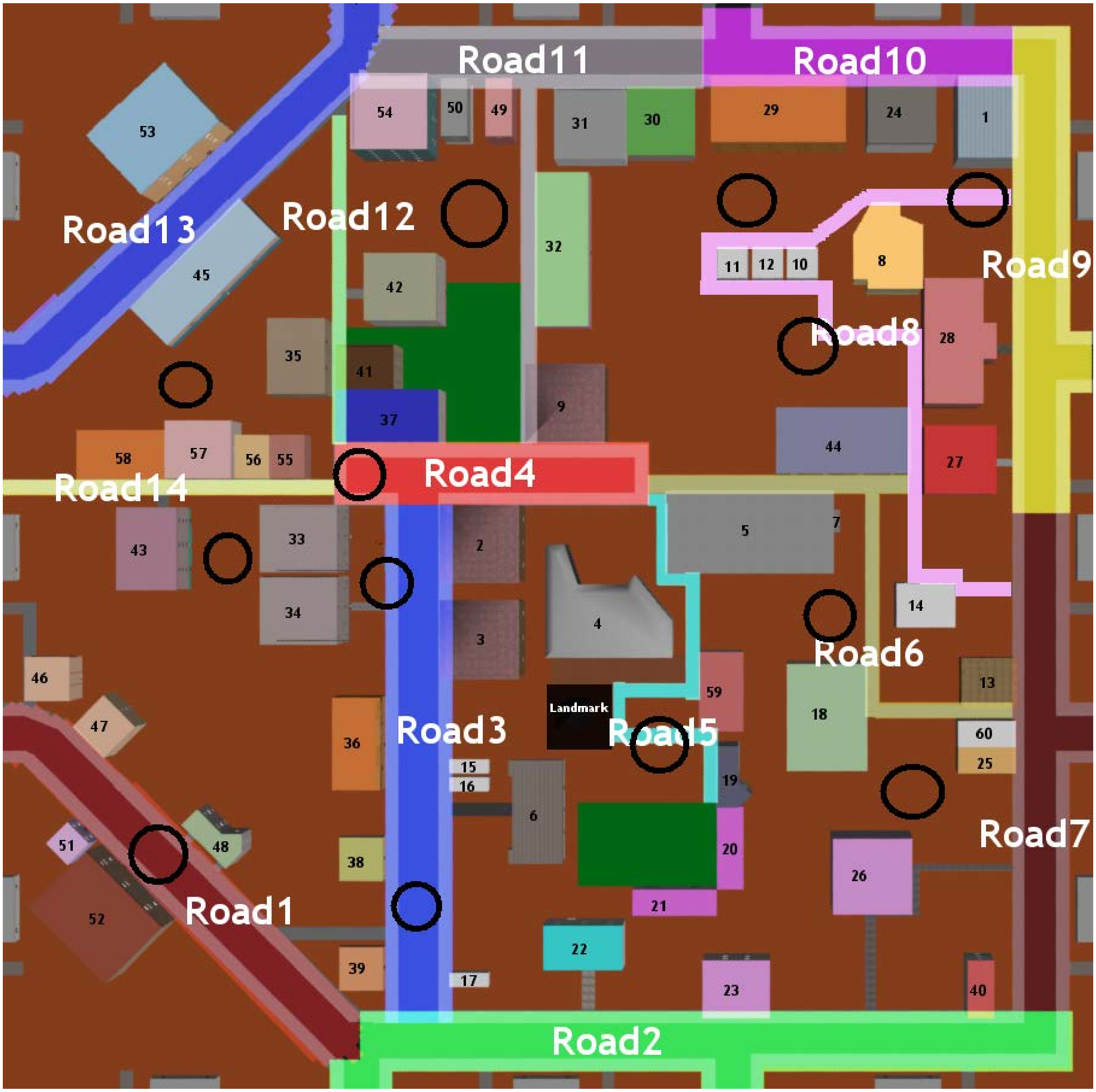

```
<?xml version="1.0" encoding="UTF-8"?>
<SniperLocations
FileName="Z:\IVP\development\ScenarioGenerator\config\Task4_1Spatial\Task4_1Spatial1.
xml">
  <SniperResult SoundFileName="z:\IVP\development\IAE\wavs\threat_084c.wav">
    <EventLocation>
      <SniperEventLocation ID="Terrain1_Location3" TileID="Roundabout" Index="2"
LocationX="-120.310000" LocationY="161.930000" LocationZ="0.000000" OrientationX="-
0.707107" OrientationY="-0.707107" OrientationZ="0.000000"></SniperEventLocation>
    </EventLocation>
    <SniperLocation>
      <SniperEventLocation ID="Terrain1_Location3" TileID="Roundabout" Index="0"
LocationX="-104.398521" LocationY="179.495588" LocationZ="5.605000" OrientationX="-
1.000000" OrientationY="0.000000" OrientationZ="-0.000000"></SniperEventLocation>
    </SniperLocation>
    <SniperEventLocation ID="Terrain1_Location3" TileID="Roundabout" Index="0"
LocationX="-104.398521" LocationY="143.695588" LocationZ="5.605000" OrientationX="-
1.000000" OrientationY="0.000000" OrientationZ="-0.000000"></SniperEventLocation>
    <SniperEventLocation ID="Terrain1_Location3" TileID="Roundabout" Index="0"
LocationX="-104.398521" LocationY="140.695588" LocationZ="5.605000" OrientationX="-
1.000000" OrientationY="0.000000" OrientationZ="-0.000000"></SniperEventLocation>
    <SniperEventLocation ID="Terrain1_Location3" TileID="Roundabout" Index="0"
LocationX="-118.440515" LocationY="131.867887" LocationZ="16.909000"
OrientationX="0.552097" OrientationY="0.833780"
OrientationZ="0.000000"></SniperEventLocation>
    <SniperEventLocation ID="Terrain1_Location3" TileID="Roundabout" Index="0"
LocationX="-104.398521" LocationY="140.695588" LocationZ="1.755000"
```

APPENDIX 5



Terrain 2X2
- includes Park, Housing Project, Roundabout, and Industrial (clockwise from Park bottom left)

Housing Project

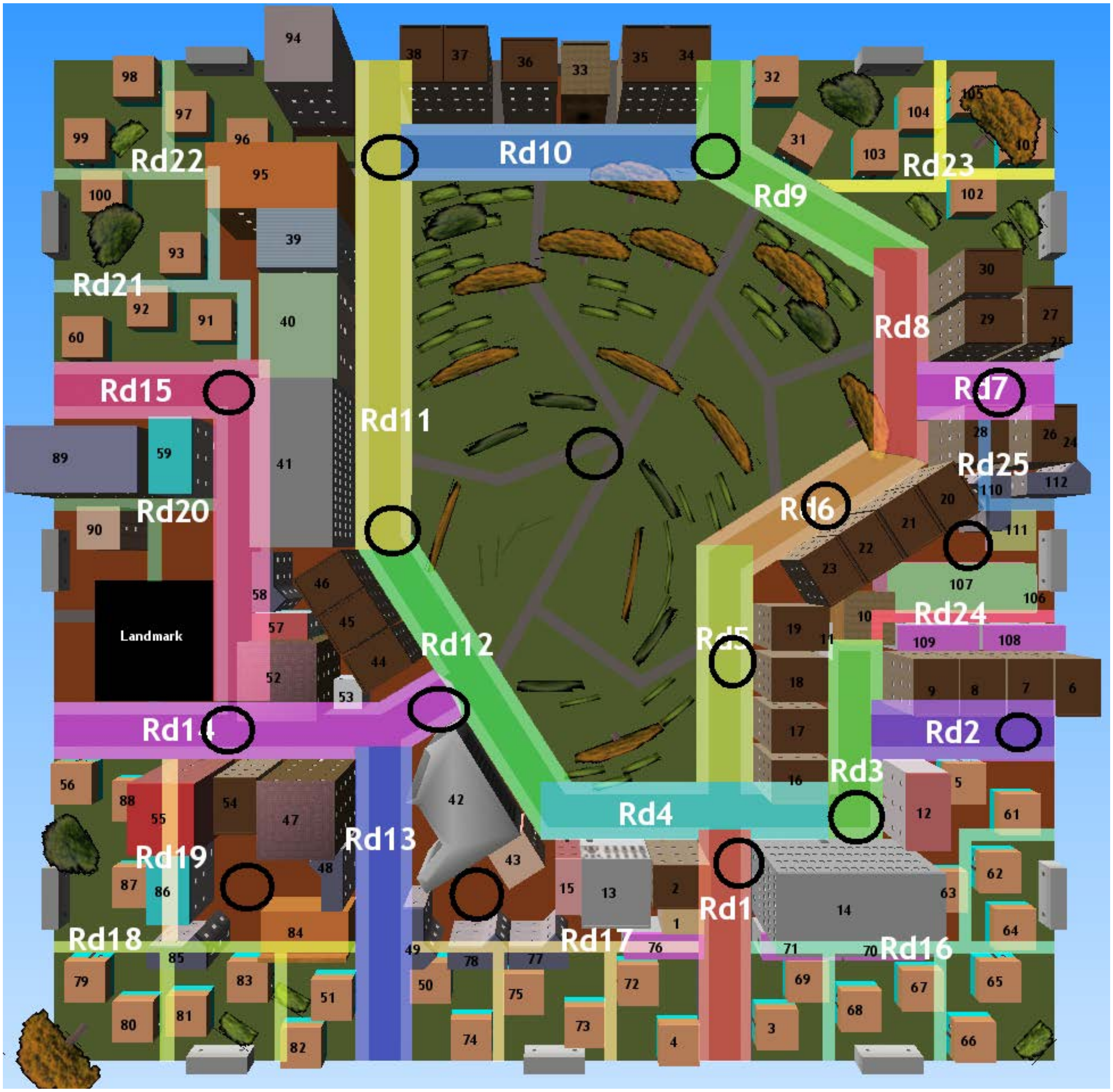


Road11
Road10
Road9
Road13
Road12
Road8
Road4
Road14
Road6
Road3
Road5
Road7
Road1
Road2
Landmark

Industrial

137
28
27
29
135
181
117
121
52
53
54
Rd14
Rd23
Rd24
138
46
47
48
49
50
142
147
145
144
Rd13
143
20
19
23
22
Rd22
122
Rd25
Rd12
146
148
163
164
155
154
153
149
115
116
123
64
119
151
Rd7
Rd11
35
34
33
32
31
96
120
161
Rd10
124
113
Rd8
118
175
40
157
17
177
66
41
156
172
39
59
176
173
171
159
158
165
166
178
162
Rd9
174
37
Rd17
160
15
65
114
94
180
38
60
100
110
179
36
Rd18
105
4
170
127
101
58
169
103
99
5
Rd5
128
129
130
126
125
2
104
56
Rd4
98
43
Rd26
6
102
24
168
Rd19
45
97
95
1
83
84
85
86
131
25
7
55
132
Rd3
109
63
67
Rd1
3
8
112
44
26
68
90
89
88
87
91
16
9
167
Rd20
106
134
133
10
108
Rd15
79
76
75
73
72
70
69
Rd16
42
93
11
82
81
80
78
77
74
71
18
14
12
13
Landmark
30
92
Rd21
61
Rd2
62
21
57
136
Rd28
Rd6
Rd27
107
139
140
141
111

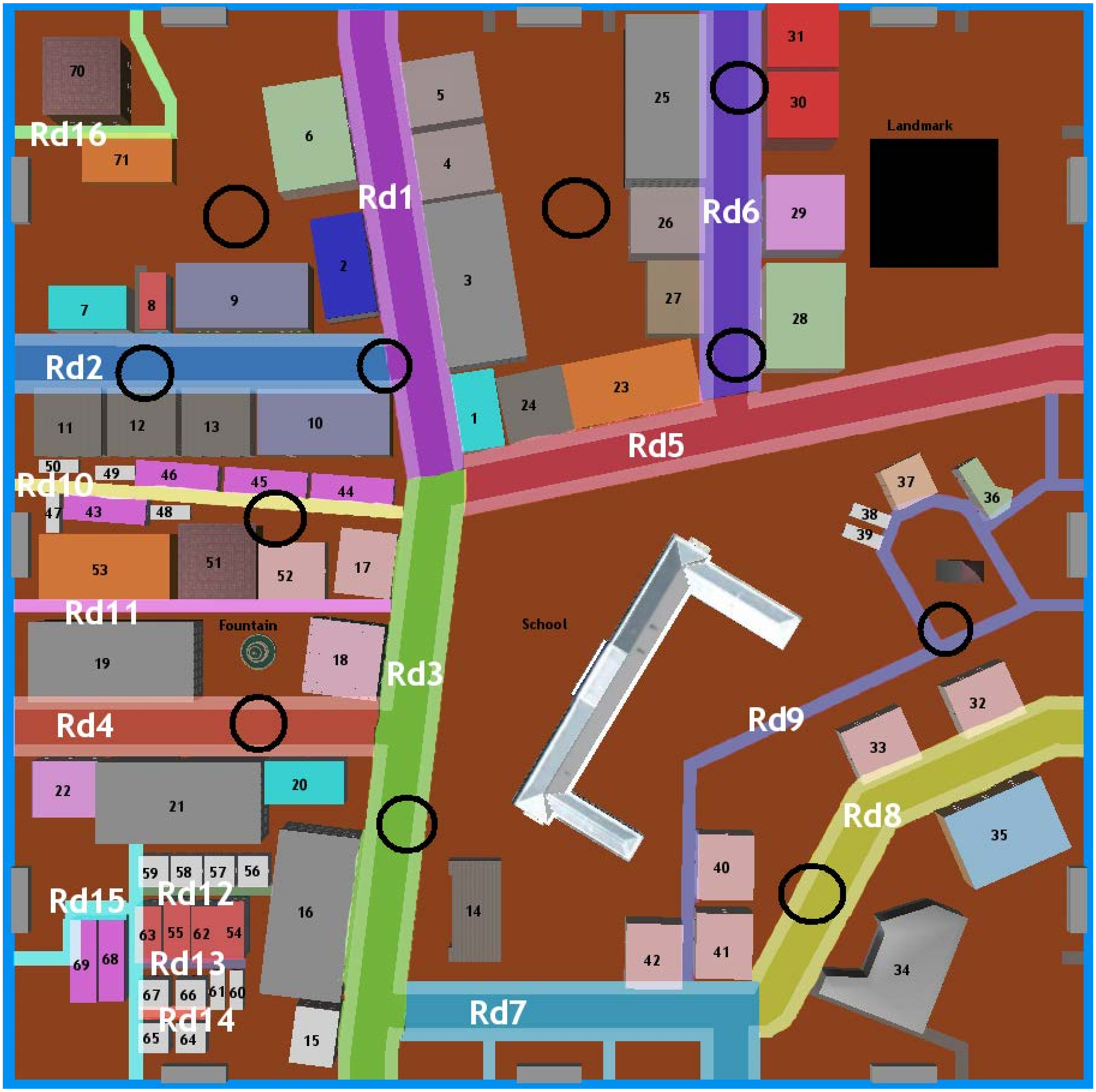
Medina


Rd10
Rd9
Rd11
Rd22
Rd23
Rd21
Rd8
Rd15
Rd7
Rd25
Rd20
Rd6
Rd24
Rd12
Rd5
Rd14
Rd2
Rd3
Rd4
Rd13
Rd19
Rd1
Rd18
Rd17
Rd16
Landmark
94
38
37
36
33
35
34
32
98
97
99
96
95
31
104
105
103
102
100
39
93
30
92
91
40
60
29
27
41
89
59
28
26
90
110
112
20
21
111
22
23
107
106
46
58
57
45
19
10
109
108
52
44
53
18
9
8
7
6
17
56
88
55
54
47
42
16
5
12
61
43
87
86
48
15
13
2
63
62
14
64
84
85
1
79
83
49
78
77
76
71
70
51
50
72
69
67
65
80
81
75
68
82
74
73
4
3
66

Park


Road11
Road7
Road6
Road12
Road8
Landmark
Road5
Road9
Road10
Road4
Road13
Road14
Road2
Mosque
Road3
Road1

Roundabout



70
Rd16
71
6
5
4
Rd1
3
2
9
8
7
25
31
30
Landmark
26
Rd6
29
27
28
Rd2
11
12
13
10
1
24
23
Rd5
50
49
46
45
44
Rd10
47
43
48
37
36
38
39
53
51
52
17
Rd11
Fountain
19
18
Rd3
School
Rd4
Rd9
32
33
22
21
20
Rd8
35
59
58
57
56
Rd15
Rd12
16
14
40
63
55
62
54
69
68
Rd13
42
41
34
67
66
61
60
Rd14
Rd7
65
64
15

School

8.0 SECTION 8: GLOSSARY

ALF - Auditory Localization Facility located at Wright Patterson Air Force Base
COTS - Commercial Off The Shelf software
CSAR - Combat Search and Rescue missions
DIS - Distributed Interactive Simulation (DIS) is an IEEE standard for conducting real-time platform-level wargaming across multiple host computers
GPS - Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information
HLA - A high-level architecture (HLA) is a general purpose architecture for distributed computer simulation systems
IVP - Integrated Virtual Platform
IVE - IVP Visual Environment
IEC - IVP Experiment Controller
IAE - IVP Audio Environment
IDB - IVP Data Base
IP - Internet Protocol
LED - Light Emitting Diode
PJ - Pararescuemen (AFSC 1T2X1) also known as "PJs" (Pararescue Jumpers) are United States Air Force Special Operations Command (AFSOC) and Air Combat Command (ACC) operatives tasked with recovery and medical treatment of personnel in humanitarian and combat environments
SLAB - SLAB is a real-time virtual acoustic environment rendering system originally developed in the Spatial Auditory Displays Lab at NASA Ames Research Center.
TCP - Transport Control Protocol
UDP - User Datagram Protocol (UDP) is one of the core members of the Internet Protocol Suite,
VOIP - Voice Over Internet Protocol
WSARC - Wright State Applied Research Corporation
WSU - Wright State University